Fisheries

Commonwealth Small Pelagic Fishery: Fishery Assessment Report 2012

T.M Ward, A.R Ivey and D. Gorman

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Report to the Australian Fisheries Management Authority

Government of South Australia

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EXECUTIVE SUMMARY

This report presents fishery statistics and synthesises existing stock assessment information for the key target species of the Commonwealth Small Pelagic Fishery (SPF). The report is a requirement at Tier 2 of the SPF Harvest Strategy 2008 (last revised April 2013).

Total catches in 2011/12 of all major species were low in a historical context due to low levels of fishing effort.

Preliminary Daily Egg Production Method (DEPM) assessments of Blue Mackerel (*Scomber australasicus*) provided a mid-range best estimate of spawning biomass of ~23,009 t in the East zone of the SPF (2003 and 2004 survey) and a best estimate of ~56,000 t in the West zone (2005 survey). Management Strategy Evaluation (MSE) suggested that the spawning biomass was higher than the DEPM estimate in each zone. Between 1997/98 and 2011/12, catches in the East ranged from ~300–1000 t, with ~251 t taken in 2011/12. In the West, catches increased rapidly after 2004 and reached ~2,000 t in 2008/09, with ~135 t taken in 2011/12. Recent annual catches have been below the maximum Recommended Biological Catch (RBC) limit at Tier 2 for each zone (3,000 t in East; 6,500 t in West). All fish sampled from catches in the West zone were above the estimated size at maturity; catches were dominated by 4 and 5 year olds. There is no evidence to suggest that recent low catches of Blue Mackerel in either zone are not sustainable.

Preliminary DEPM assessments of Jack Mackerel (*Trachurus declivis*) in the East zone derived from samples collected during October 2002 estimated a spawning biomass of ~114,900–169,000 t (median 141,500 t). Off Tasmania, catches peaked at ~40,000 t in 1986/87, but have not exceeded ~3,000 t since 2003/04. Negligible landings of Jack Mackerel were made in 2011/12 (58 t). Catches in the West have not exceeded 500 t in the period since 1997/98. The abundance of older age classes in purse seine catches off Tasmania declined between the mid–1980s and mid–1990s, potentially indicating a fishery impact on population structure. Coupled with large declines in historical catches, this situation gave rise to concern about the status of Jack Mackerel in the East. However, since the mid–1990s, fishing effort and catches have remained at relatively low levels. There is no evidence to suggest that recent low catches of Jack Mackerel in either zone are not sustainable.

A trend identified in this report was the increases in yellowtail scad (principally in NSW) that has apparently resulted from the entry of a number of new purse seiners. Catches were >400 t in 2010/11 and 2011/12

Preliminary DEPM estimates for Redbait (*Emmelichthys nitidus*) in the East based on samples collected in 2005 and 2006 suggest a spawning biomass in excess of 50,000 t, implying that catches during the early 2000s (~7,000 t each year) were sustainable; this conclusion was supported by the outputs from the MSE. There were no redbait catches reported for 2011/12 in either zone. While no biomass estimate is available for the West, fishing has been limited to a small area (off SW Tasmania), suggesting that fishing pressure on this stock has been low. Biological sampling in the East revealed no obvious impact on size or age composition over the recent history of the fishery. There is no evidence to suggest that recent low catches of Redbait in either zone are not sustainable.

The best estimate of spawning biomass of Australian Sardine (*Sardinops sagax*) off eastern Australia during July 2004 was ~29,000 t. Only unlikely values of mean daily egg production and spawning fraction produced estimates outside the range of 25,000–35,000 t. The MSE estimate of spawning biomass was similar to the DEPM estimate. Catches of Australian Sardine in the East remained below 1,000 t up to 2001, but have exceeded 2,000 t since 2004/05 and reached almost 5,000 t in 2008/09. In 2011/12, the catch of Australian Sardine in the East was 2,022 t. The highest annual catch in the East (~5,000 t) was ~17% of the best estimate of spawning biomass (~29,000 t based on samples collected in 2004). There is no evidence to suggest that the current catch level of Australian Sardine in the East is unsustainable. However, recent catches have been at a level where regular stock assessment using the DEPM is warranted.

There is no evidence to suggest that recent catch levels of any SPF quota species are not sustainable. However, most estimates of spawning biomass are more than five years old. Consideration should be given to updating DEPM assessments for all species in each zone. The large size of the West zone makes assessment of that area logistically difficult. Consideration should be given to sub-dividing the West zone for the purposes of stock assessment and management.

ACKNOWLEDGEMENTS

Data presented in this report were supplied by: Patricia Hobsbawn and John Garvey (Australian Bureau of Agricultural and Resource Economics and Sciences); Dr Jeremy Lyle (Institute for Marine and Atmospheric Studies); Dr John Stewart (New South Wales Department of Primary Industries); and Kylie Hall (Fisheries Victoria). This report was formally reviewed by Dr Greg Ferguson and Dr Stephen Mayfield (SARDI Aquatic Sciences) and approved for release by Professor Xiaoxu Li (SARDI Aquatic Sciences).

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1 GENERAL INTRODUCTION

1.1 Background to Small Pelagic Fishery (SPF)

The Commonwealth Small Pelagic Fishery (SPF), managed by the Australian Fisheries Management Authority (AFMA), is a purse seine and mid-water trawl fishery extending from southern Queensland to southern Western Australia. There are currently 71 licences and 5 active vessels operating in this fishery targeting several species including Jack Mackerel *Trachurus declivis*, Redbait *Emmelichthys nitidus*, Blue Mackerel *Scomber australasicus,* and Australian Sardine *Sardinops sagax.* Yellowtail Scad, *Trachurus novaezelandiae,* is taken as by-product. SPF species are also taken in several State and Commonwealth managed fisheries. Key events in the history of the SPF are listed in Woodhams *et al.* (2012).

1.2 Harvest Strategy

The SPF is managed by a combination of input and output controls that include limited entry, zoning, mesh size restrictions, and total allowable catch (TAC) limits (AFMA 2008; Woodhams *et al.* 2012). A new Management Plan was implemented in 2009 that established Eastern and Western management sub-areas (zones, hereafter East and West) rather than the previous four (Fig. 1.1, AFMA 2009) and introduced some new controls such as Individual Transferable Quotas (ITQs).

There is a tiered Harvest Strategy (HS) with prescribed levels of assessment and monitoring required at each Tier (AFMA 2008; Woodhams *et al.* 2012). Recommended Biological Catches (RBCs) are determined by the SPF Resource Assessment Group (SPFRAG).

<u>Tier 1:</u> RBCs for each Tier 1 species in each zone are set at 10–20% of the median spawning biomass estimated using the Daily Egg Production Method (DEPM). The exploitation rate applied each season is determined by the SPFRAG based on the time period since the last DEPM (as outlined in the HS) and annual assessments of catch/effort data and size/age structure of catches.

<u>Tier 2:</u> Maximum RBCs for each Tier 2 species in each zone are specified based, where possible, on approximately 7.5% of the median spawning biomass estimate. RBCs are determined by the SPFRAG on the basis of old (>5 years) DEPM estimates and annual assessments of catch/effort data and size/age structure of catches. Current Tier 2 RBCs for each zone/species are shown in Table 1.1.

<u>Tier 3:</u> Maximum RBCs for Tier 3 species in each zone may not exceed 500 t. RBCs are determined by SPFRAG on the basis of catch and effort data.

Table 1.1 Tier 2 maximum RBC values for the West and East zones of the Small Pelagic Fishery (from AFMA 2008).

Species	Western Zone (t)	Eastern Zone (t)
Redbait	5,000	5,000
Blue mackerel	6,500	3,000
Jack mackerels	5,000	10,600
Australian sardine	N/A	3,000

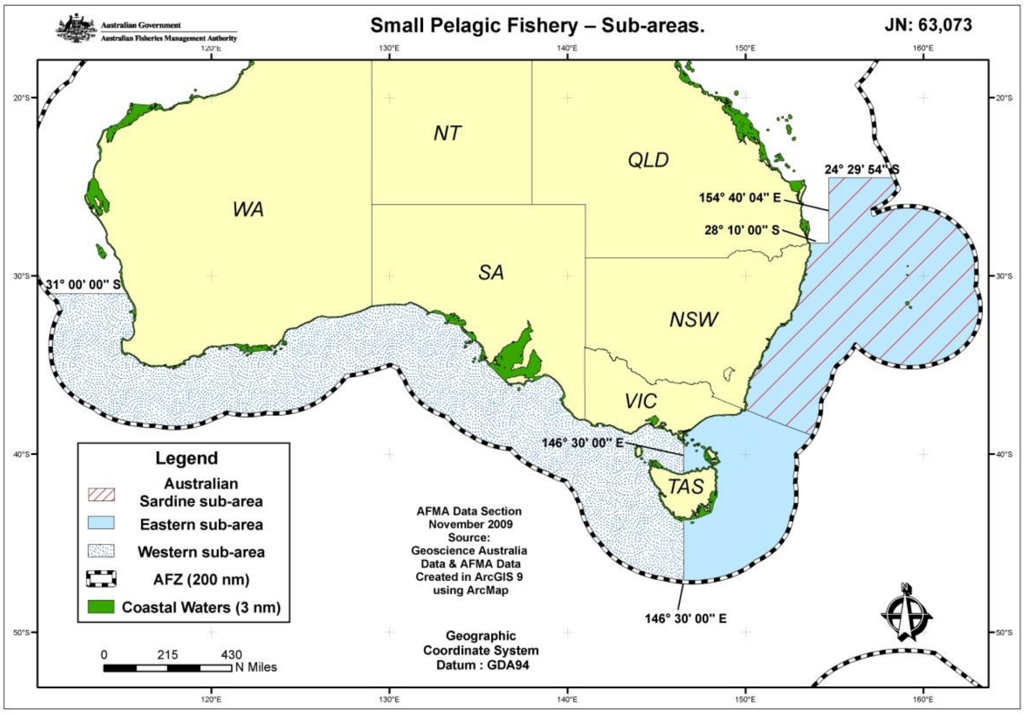

Figure 1.1 Management sub-areas of the Commonwealth Small Pelagic Fishery.

1.3 Previous Assessments

DEPM surveys have been conducted for Blue Mackerel East and West (Ward and Rogers 2007; Ward *et al.* 2009), Australian Sardine East (Ward and Rogers 2007), Redbait East (Neira *et al.* 2008), Jack Mackerel East (Neira 2011) and Yellowtail Scad East (Neira 2011). Management Strategy Evaluations (MSEs) have been conducted by the Australian Bureau of Agricultural and Resource Economics and Sciences (ABARES; Giannini *et al.* 2010). This report updates annual assessments of the SPF conducted by Ward *et al.* (2010, 2011).

1.4 Aims and Objectives

This report collates and presents 2011/12 catch/effort and biological data for each of the quota species in the SPF. Biomass estimates and MSEs are also included where available. The report satisfies the requirements of the SPF Harvest Strategy (AFMA 2008).

2 BLUE MACKEREL (*SCOMBER AUSTRALASICUS*)

2.1 Introduction

2.1.1 Background to Fishery

Large fisheries for *Scomber spp.* (i.e. ~50,000 to 500,000 t per annum) are located off Japan, Peru, China, Korea, Russia, and the Ukraine (Ward *et al.* 2001). The largest fishery for Blue Mackerel is based in New Zealand where annual catches range between approximately 9,000 and 14,000 t per annum. Blue Mackerel is taken in several fisheries in Australia with total annual catches usually less than 3,000 t (Ward *et al.* 2001).

Blue Mackerel is predominately taken in the SPF but also in the Great Australian Bight Trawl (GAB), Gillnet Hook and Trap (GHT), Southern and Western Tuna and Billfish (SWTBF and WTBF), Eastern Tuna and Billfish (ETBF) and the South East Trawl (SET) fisheries (Ward and Rogers 2007). Relatively small quantities of Blue Mackerel are taken in South Australia by Marine Scalefish Fishery (MSF) licence holders using pole, hand-line, troll-line, long-line, gill-net, shark-net, bait-net and purse seine nets (Ward and Rogers 2007). The New South Wales (NSW) commercial purse seine fishery has targeted Yellowtail Scad and Blue Mackerel since the early 1980s (Stewart and Ferrell 2001). Blue Mackerel typically comprise ~38% of the catches. The average annual catch of Blue Mackerel in Victorian waters between 1978/79 and 2004/05 was 49 t (±22.9) with catches varying between 0.2 to 370.6 t per annum (Ward and Rogers 2007).

The Tasmanian Purse Seine Fishery has recorded catch and effort data since its inception in 1984. Logbooks contained a shot by shot record of fishing operations and species taken. The first reported landings of Blue Mackerel occurred during the 1985/86 season but limited species-specific information was recorded (Ward and Rogers 2007). Blue Mackerel represented ~2–3.7% of catches between 1986 and 1989. Species-specific information was not available during the other years.

Blue Mackerel is taken in a multi-species fishery in Western Australia using a variety of gear types, which include purse seine, beach seine, trawl, gill and haul nets, fishing poles and drop lines (Ward and Rogers 2007).

Most (75%) of the national recreational harvest of Blue Mackerel (estimated annual catch 569,319 fish) was taken in NSW, with 14% and 8% taken in Western Australia and South Australia, respectively. Victoria, Tasmania and Queensland made up the remaining 3% of the recreational catch (Henry and Lyle 2003).

2.1.2 Taxonomy

Mackerels fall within the genus *Scomber* that has traditionally included three species: Blue Mackerel *S. australasicus*, Chub Mackerel *S. japonicus*, and Atlantic Mackerel *S. scombrus*. However, Scoles *et al*. (1998) showed that *S. australasicu*s and *S. japonicus* are more closely related to each other than to *S. scombrus*, and that morphological and genetic differences in Atlantic and Indo-Pacific populations of *S. japonicus* may warrant recognition of two separate species. Analyses by Infante *et al.* (2006) support this claim and a separate species *S. coli* has been established to replace *S. japonicus* in the Atlantic Ocean. Under these definitions, there are two closely related species, *S. japonicus* and *S. australasicus,* in the Indian and Pacific Oceans, and *S. scombrus* and *S. coli* in the Atlantic Ocean.

2.1.3 Distribution

Blue Mackerel occur throughout the Pacific Ocean including South East Asia, Australia and New Zealand and in the northern Indian Ocean and Red Sea. In Australia it is found mainly in southern temperate and subtropical waters between southern Queensland and Western Australia (Ward *et al.* 2001). Juveniles and small adults usually occur in inshore waters and larger adults form schools in depths of 40–200 m across the continental shelf (Kailola *et al.* 1993).

2.1.4 Stock Structure

The stock structure of Blue Mackerel in Australasian waters is uncertain. One study found significant differences between Australia and New Zealand in the morphology of monogenean parasites (Rohde 1987). However, Scoles *et al.* (1998) found no genetic differences between Blue Mackerel from Australia and New Zealand using mtDNA RFLP analysis and cytochrome *b* sequencing. A recent study into stock structure of Blue Mackerel (Ward and Rogers 2007) found populations across Australia were significantly different for both parasite and otolith analyses, with a small amount of overlap between adjacent sampling locations (WA and SA, SA and Qld) and less between distant locations (WA and Qld).

2.1.5 Movement

Little is known about the movement patterns of Blue Mackerel in Australian waters.

2.1.6 Food and Feeding

Mackerel (*Scomber* spp.) have been found to alter their feeding behaviour and ingestion rates depending on prey size and density and to consume their own larvae (Prokopchuk and Sentyabov 2006; Garrido *et al.* 2007). A recent study of the diet of small pelagic fish off South Australia (SA) found the diet of Blue Mackerel to be dominated by krill and larval fish (Daley, SARDI Aquatic Sciences unpublished data).

2.1.7 Age, Growth and Size

Like many other pelagic fishes, it is challenging to age Blue Mackerel using standard approaches as the majority of otoliths are difficult to read and these difficulties increase with fish age (Ward and Rogers 2007). Growth rates and trajectories of males and females from waters off South Australia are similar. Juveniles of both sexes grow rapidly, and reach ~250 mm fork length (FL) after ~2 years. Stevens *et al.* (1984) found that Blue Mackerel attained sizes of up to 440 mm FL in the Great Australian Bight (GAB) and estimated that fish were aged up to ~8 years. Stewart *et al.* (1999) showed that off eastern Australia an opaque zone is deposited during winter in the otoliths of one-year old Blue Mackerel, and that zones became visible in early summer (Stewart *et al.* 1999). Stewart and Ferrell (2001) estimated the ages and growth rates of Blue Mackerel taken off southern NSW in commercial purse seine operations and in a fishery-independent sampling program. Most fish in the commercial catches were 1–3 years old and the maximum age was ~7 years.

2.1.8 Reproduction

Approximately 50% of male and female Blue Mackerel are sexually mature at 237 and 287 mm FL, respectively. Blue Mackerel are serial spawners, spawning multiple times over a prolonged spawning season (Ward and Rogers 2007; Rogers *et al.* 2009). Spawning in southern Australia occurs from summer to early autumn and late winter to spring in NSW (Ward and Rogers 2007). Mean spawning frequencies range from 2 to 11 days in southern Australia. Mean batch fecundity is ~70,000 oocytes per batch and 134 oocytes per gram of weight. Fecundity increases exponentially with fish length and weight. Most of the eggs collected off southern Australia have been obtained from the mid-continental shelf. High egg and larval densities are recorded at depths of 40–120 m with sea surface temperatures (SSTs) of 18–22°C. The location of spawning off southern Australia appears to vary substantially between years. Results of an exploratory survey suggest that the western GAB is an important spawning area, however this region has not yet been sampled intensively (Ward and Rogers 2007).

2.1.9 Early Life History and Recruitment

Blue Mackerel eggs are transparent and spherical, measure 0.80–1.35 mm in diameter, possess a smooth chorion and prominent, unsegmented yolk with a single, 0.22–0.38 mm diameter oil globule (Ward and Rogers 2007). Blue Mackerel yolksack larvae are <3.2 mm TL at hatching (Neira *et al.* 1998) and metamorphose at lengths of ~23.3 mm TL.

2.1.10 Stock Assessment

An extensive study investigated the application of the egg based stock assessment methods on Blue Mackerel and concluded that the species was amenable to assessment using the Daily Egg Production Method (Ward and Rogers 2007; Ward *et al.* 2009).

2.2 Methods

2.2.1 Fishery Statistics

Fishery statistics were supplied by the ABARES up to 2010/11 and in 2011/12 data were supplied by relevant jurisdictions and collated by SARDI Aquatic Sciences. Annual data are reported by financial years.

2.2.2 Biological Information

No biological data were available for Blue Mackerel during the 2011/12 financial year. Samples of Blue Mackerel from the West for seasons between 2008/09 and 2010/11 were supplied by the commercial purse seine fishery operating from Port Lincoln, South Australia. No fine scale spatial or temporal information was available for these samples, although the fish were caught in summer/early autumn. Fish were dissected and otoliths were weighed and read (ring count and a readability index assigned) at SARDI Aquatic Sciences. Reproductive indices were determined after Ward and Rogers (2007).

2.2.3 Biomass Estimates and MSE

A preliminary biomass estimate for Blue Mackerel was obtained for each of the management regions during a study between 2003 and 2005 (Rogers and Ward 2007).

A MSE model was used to test a range of management/harvest scenarios under the SPF harvest strategy for all stocks (Giannini *et al.* 2010). In most scenarios, the 30 year simulation period used in the MSE was sufficient for each stock to reach equilibrium, and generally this was well above 20% of virgin biomass levels (B_{20}). Sensitivities of the model to the various input parameters were also tested. The model was found to be most sensitive to the assumed stock-recruitment relationship and natural mortality. The model was re-examined in 2011 to address concerns about values used for number of recruits.

2.3 Results

2.3.1 Fishery Statistics East / West

2.3.1.1 Location of vessels

The number of vessels that reported landings of Blue Mackerel in the East was substantially greater than the long-term average, although the majority of these were still based in NSW (Fig. 2.1). This contrasted the West, where the number of vessels was the lowest previously reported and comprised records from South Australia and Victoria (Fig. 2.2).

2.3.1.2 Annual Patterns-catch, effort & catch-per unit effort (CPUE)

In 2011/12 catches of Blue Mackerel in the East (251 t) were the lowest reported over the previous 15 years (Fig. 2.3, note that analysis is currently limited by incomplete catch data from Tasmania). Additionally, the absence of monthly effort data from NSW means that fishing effort (i.e. vessel days) cannot be determined for the 2011/12 financial year. Historically, fishing effort has declined from highs in the late 1990s and early 2000s (~3,000 vessel days), to levels <2500 vessel days in 2009/10 and 2010/11 (Fig. 2.3). The absence of data on effort precluded the calculation of CPUE for 2011/12. Prior to this CPUE remained stable at ~0.2 t per fishing day between 1998/99 and 2006/07 (Fig. 2.4) then dropped to below 0.1 in 2007/08 and has since sustained an incremental increase returning to ~0.2 in 2010/11.

Catches of Blue Mackerel have been more variable in the West than the East with reported landings below 100 t from 1997/98 and 2003/04 (Fig. 2.5), prior to large increases in 2005/06 and 2006/07 (>1,500 t) and a peak in 2008/09 (~2,000 t). The greatest variation in annual catch has occurred over the last four seasons, where landings have decreased consecutively to their lowest level in 8 years (i.e. 2011/12; 136 t; Fig. 2.5). Over the last 15 years, fishing effort has varied between ~20 to 165 vessel days, with a recent gradual decline resulting in the second lowest values on record for 2011/12 (Fig. 2.5). CPUE remained <1 t per vessel day between 1997/98 and 2003/04 and increased rapidly to ~14 t per vessel day in 2005/06 (Fig. 2.6). Subsequent catch rates remained generally high (except for 2007/08) until 2011/12 (Fig. 2.6).

2.3.1.3 Intra-annual Patterns-catch and effort

Intra-annual trends in catch and effort in the East are unavailable for the 2011/12 fishing year because of an absence of monthly catch and effort data for individual vessels based in NSW and Tasmania (i.e. less than 5 vessels requires data to be treated as confidential). Previously, these data have been highly variable with catches occurring in all months for all seasons from 1997/98 to 2010/11 (Fig. 2.7). Presentation of intra-annual data on catch and effort in the West (Fig. 2.8) were (and have historically been) affected by confidentiality issues.

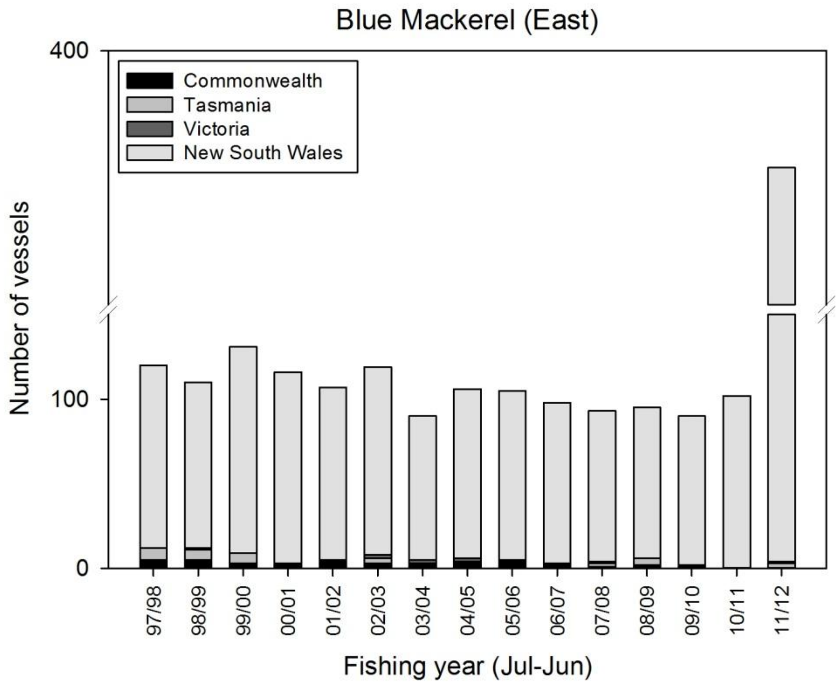

Figure 2.1 Number of vessels which landed Blue Mackerel in the East, from each of the participating management jurisdictions.

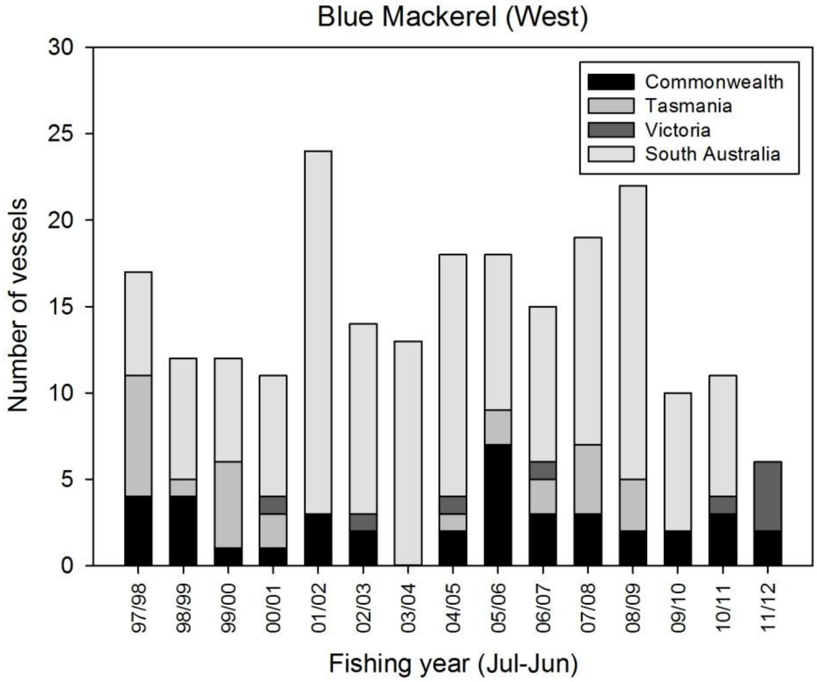

Figure 2.2 Number of vessels which landed Blue Mackerel in the West, from each of the participating management jurisdictions.

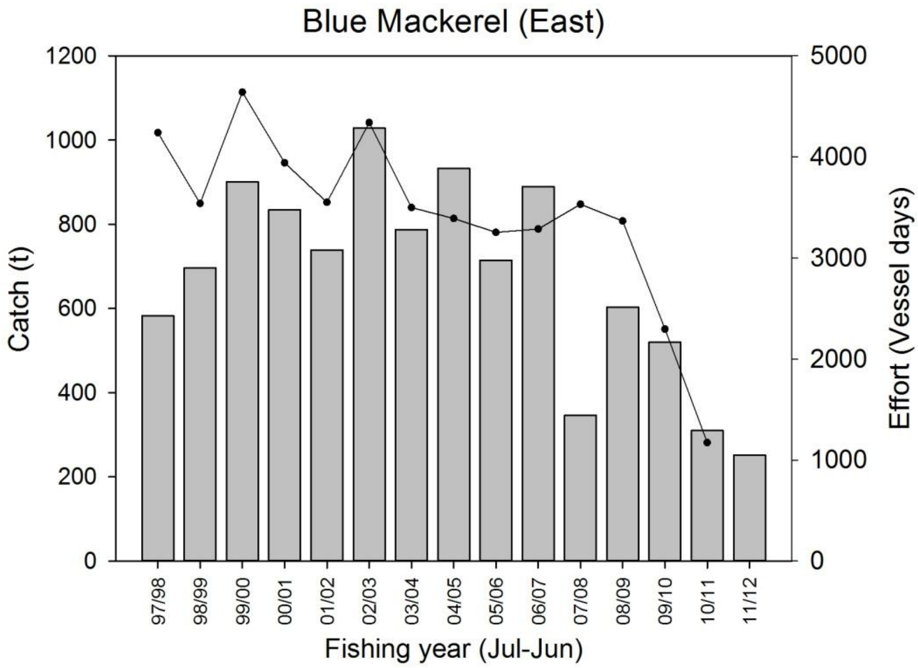

Figure 2.3 Total landed catch (t, bars) and effort (vessel days, line) for Blue Mackerel in the East during financial years over the period 1997/98–2011/12. Note no data for vessel days for 2011/12.

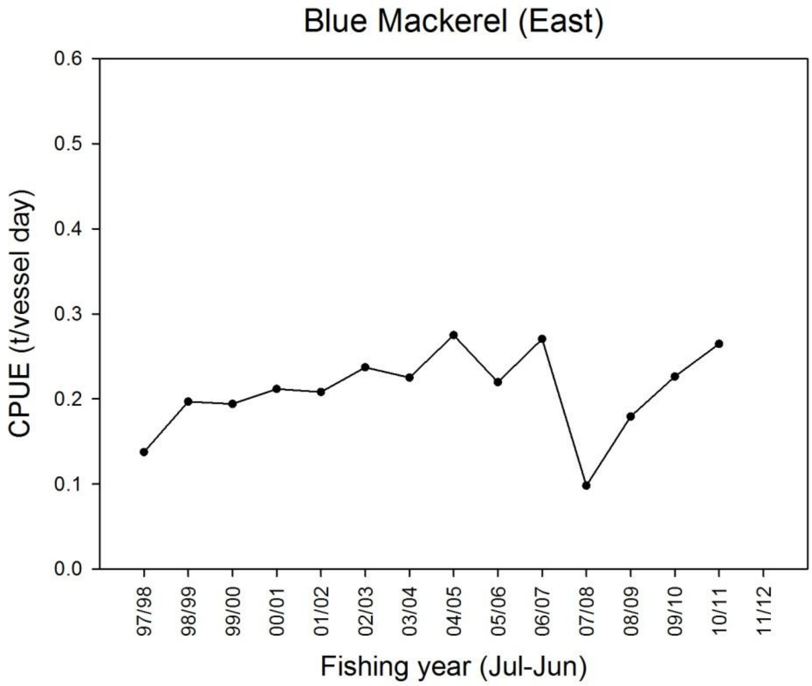

Figure 2.4 CPUE (t per vessel day) for Blue Mackerel in the East during financial years over the period 1997/98–2010/11.

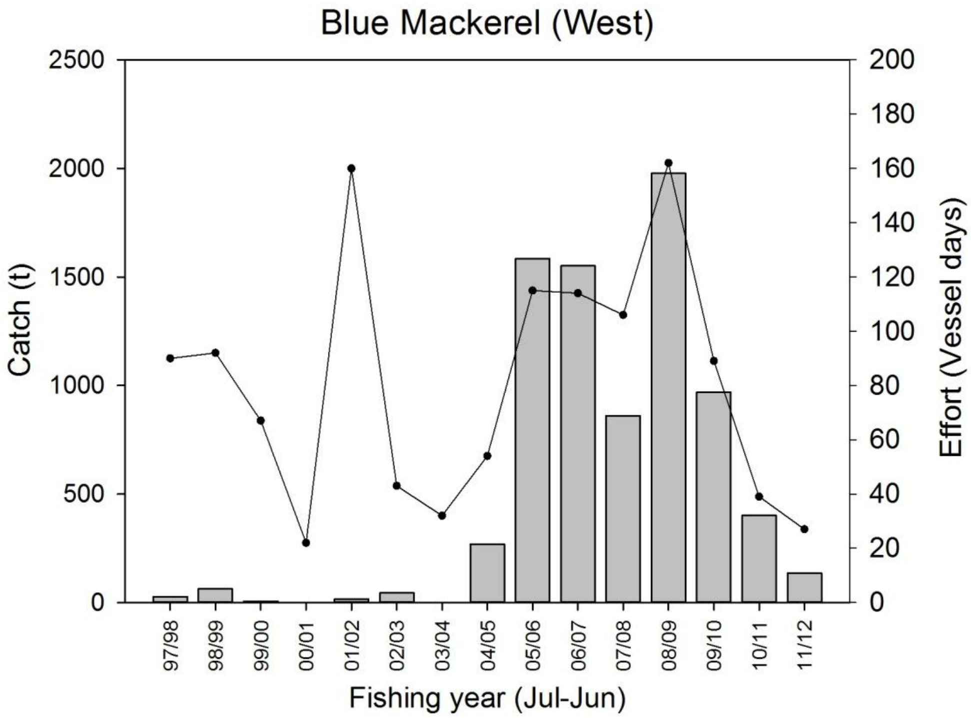

Figure 2.5 Total landed catch (t, bars) and effort (vessel days, line) for Blue Mackerel in the West during financial years over the period 1997/98–2011/12.

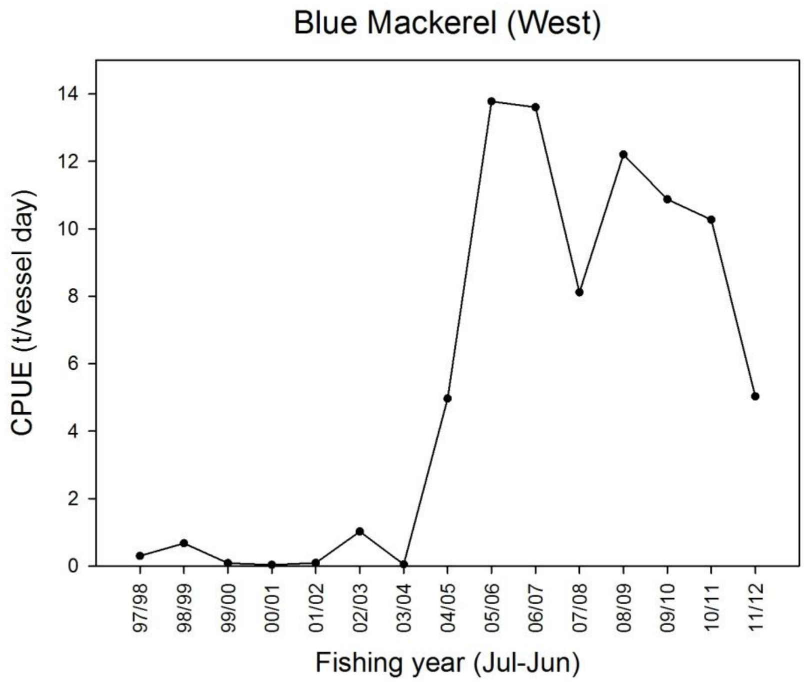

Figure 2.6 CPUE (t per vessel day) for Blue Mackerel in the West during financial years over the period 1997/98–2011/12.

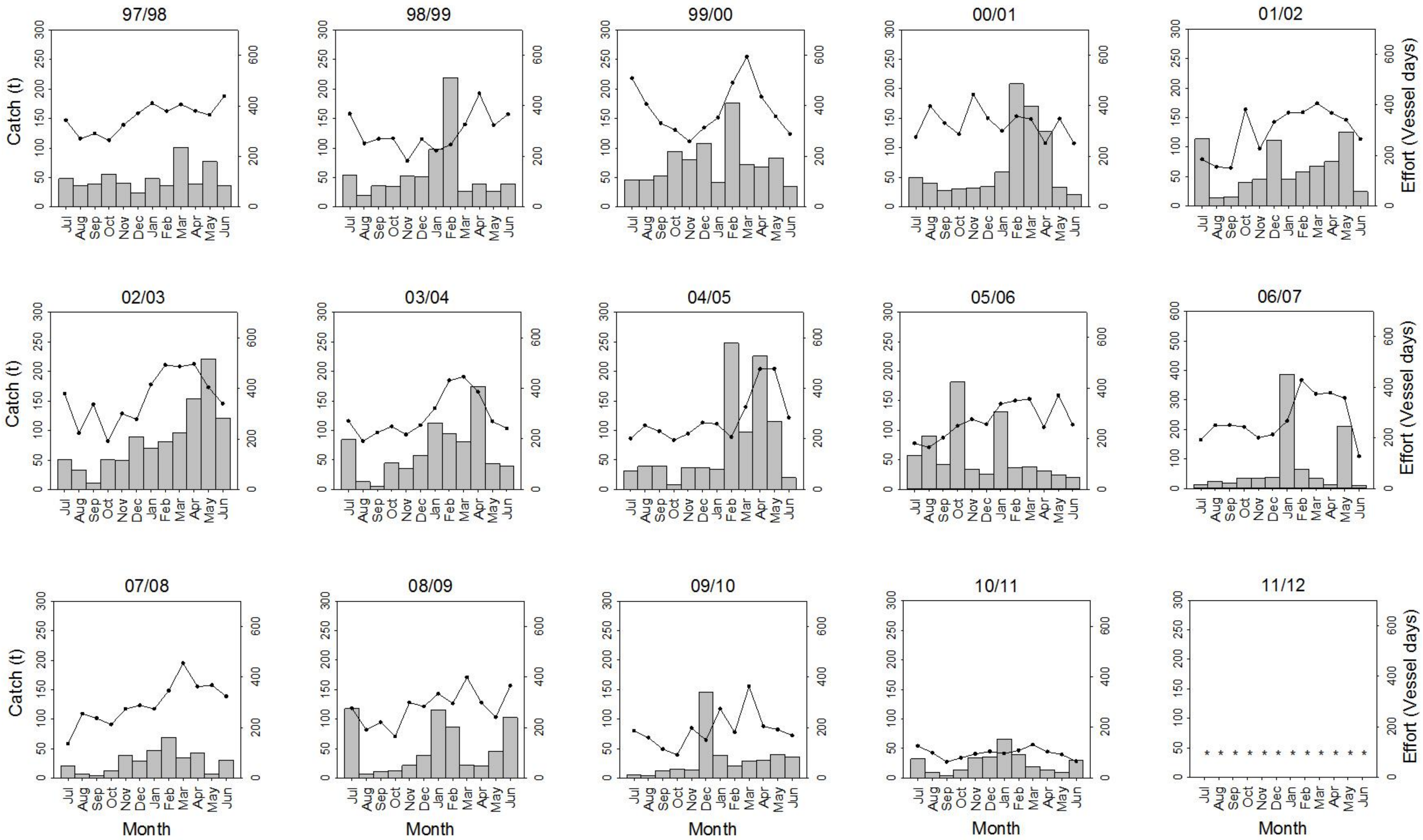

Figure 2.7 Intra-annual patterns of catch (bars) and effort (lines) for Blue Mackerel in the East for the period from 1997/98 to 2011/12. (*) indicates data confidentiality, where <5 license holders report landings from individual month.

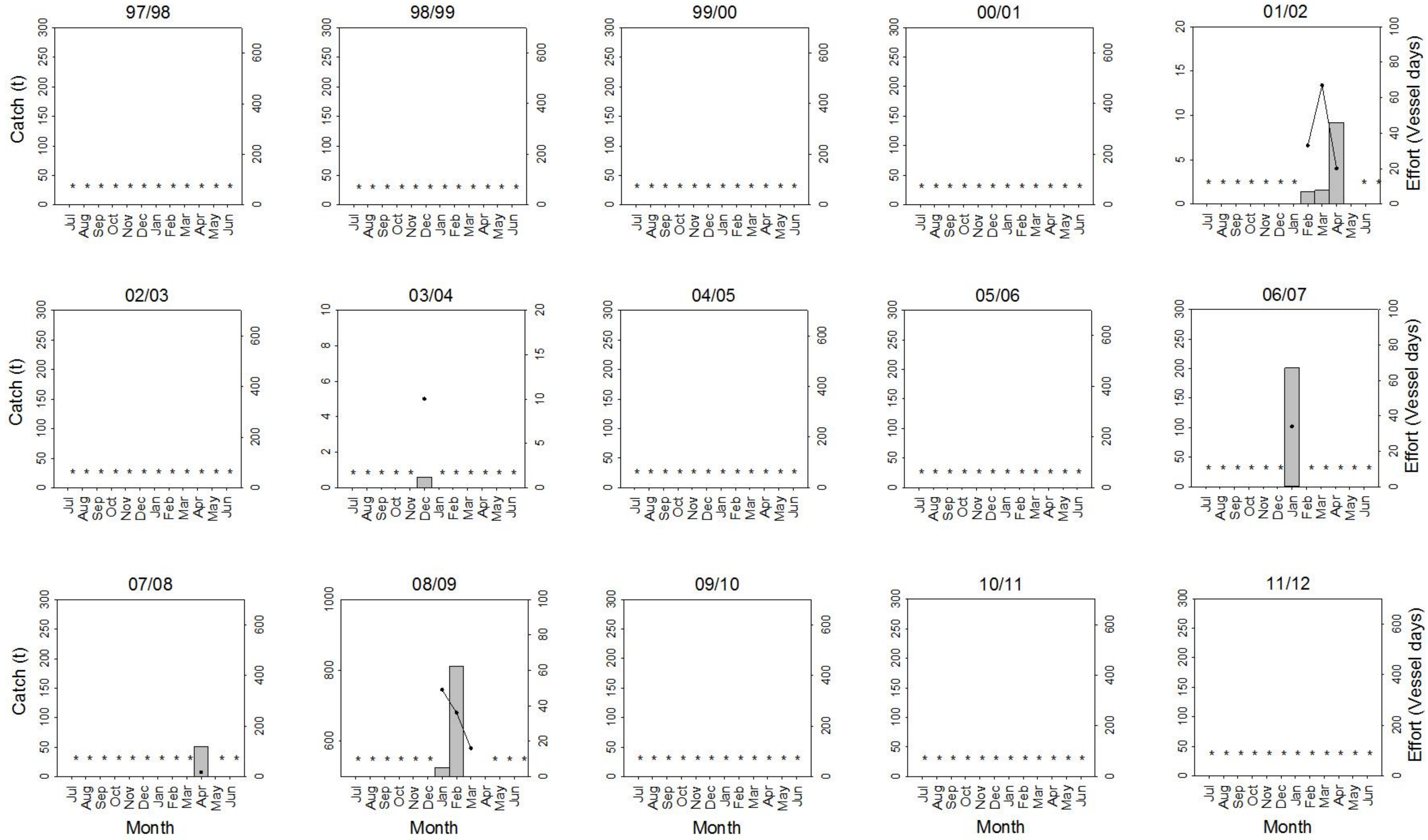

Figure 2.8 Intra-annual patterns of catch (bars) and effort (lines) for Blue Mackerel in the West for the period from 1997/98 to 2011/12. (*) indicates data confidentiality, where <5 license holders report landings from individual month.

2.3.2 Biological Information

2.3.2.1 Sample Summary

A total of 79 Blue Mackerel caught in the 2008/09, 933 in the 2009/10 and 245 in the 2010/11 fishing seasons were supplied by fish processors in Port Lincoln (West) for biological analysis. The male to female sex ratios for each year were 1:1, 0.9:1 and 0.9:1, respectively. No samples were collected in 2011/12.

2.3.2.2 Size Frequency

Fish sampled in the 2008/09 season ranged from 316–390 mm FL (Fig. 2.9) and >50% of fish were between 340 and 370 mm FL. In the 2009/10 and 2010/11 season fish ranged from 300–400 mm. No fish were below the size at 50% maturity (237 mm FL for males and 287 mm FL for females; Ward and Rogers 2007).

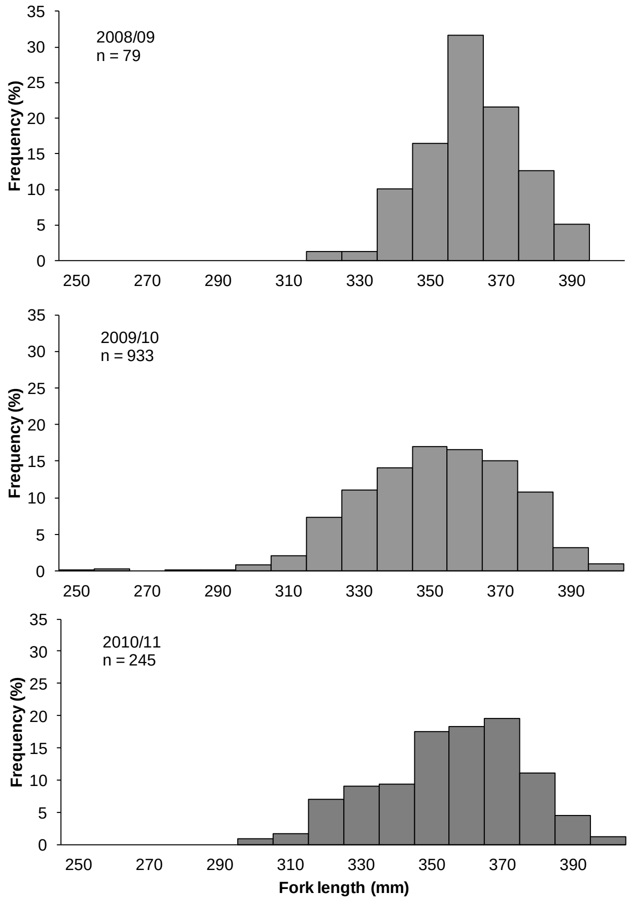

Figure 2.9 Blue Mackerel size frequency for research samples collected from commercial purse seine shots in South Australia from 2008/09 to 2010/11.

2.3.2.3 Age Structure

The otolith weight-age relationship of Ward and Rogers (2007) was applied to the otolith weights to assign ages. Ages for the 2008/09 samples ranged from 3 to 6 year olds (Fig. 2.10) and 82% of fish were 4 and 5 years old. A similar age structure was identified in 2009/10 and 2010/11, however there was a greater range of ages. In all years the majority of fish were greater than three years old.

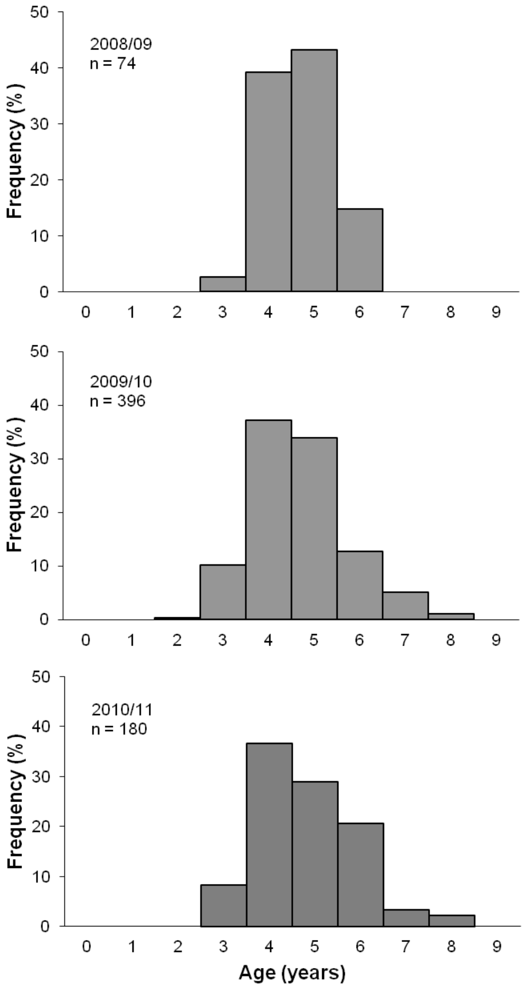

Figure 2.10 Age frequency distribution for Blue Mackerel landed in Port Lincoln during the 2008/09, 2009/10 and 2010/11 seasons, based on the otolith weight, age relationship in Ward and Rogers (2007) for South Australia.

2.3.2.4 Gonad stages

Although none of the fish sampled were below the size at maturity reported in Ward and Rogers (2007), 50% and 30.8% of males and females respectively, were immature in the 2008/09 sample (Stage 1, Fig. 2.11). Females were generally at a more advanced stage of gonad development with a higher proportion at Stage 2 and

Stage 3 (53.8% and 15.4% vs. 42.5% and 7.5%, respectively). A greater proportion of fish were at a more advanced stage of development in 2009/10 and 2010/11, with stage 3 gonads dominating the sample for both males and females (Fig. 2.11).

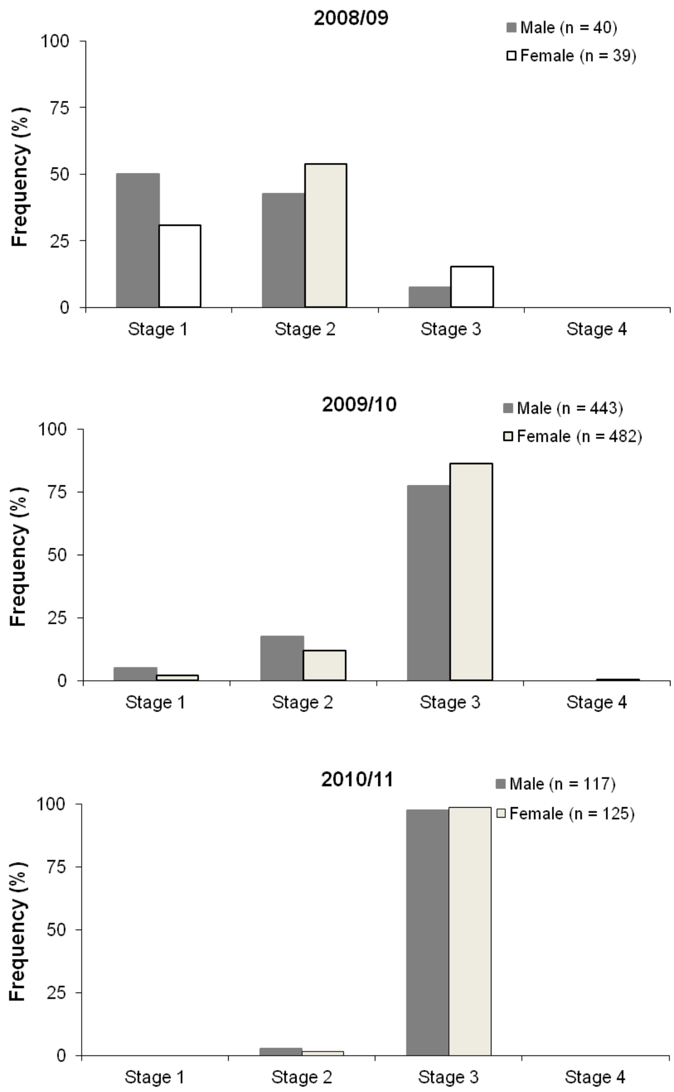

Figure 2.11 Distribution of gonad developmental stage for Blue Mackerel landed in Port Lincoln during the 2008/09, 2009/10 and 2010/11 seasons.

2.3.2.5 Size at maturity

There was an insufficient number and size range of samples to determine size at maturity (all fish above size at maturity reported in Ward and Rogers (2007)).

2.3.2.6 Gonosomatic index (GSI)

No seasonal GSI data were available for Blue Mackerel. In 2008/09, the average GSI for both sexes was 0.94% of body mass (Fig. 2.12). In 2009/10 the average GSI was

~5% (Fig. 2.12). In 2010/11, the average GSI was higher again at 7.0% and 6.1% for males and females, respectively (Fig. 2.12).

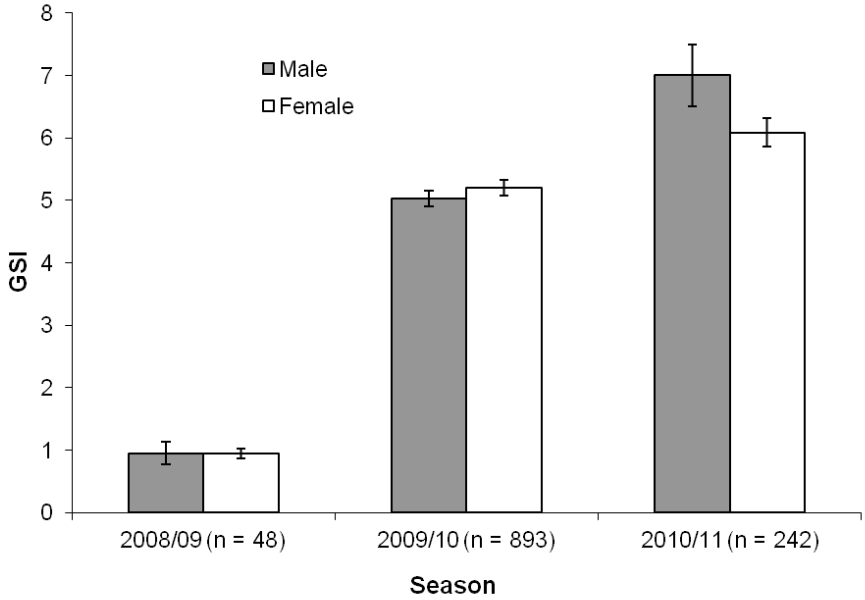

Figure 2.12 Gonosomatic index for Blue Mackerel landed in Port Lincoln during the 2008/09, 2009/10 and 2010/11 seasons, error bars are standard error. Calculated excluding Stage 1 fish.

2.3.2.7 DEPM

Preliminary estimates of the spawning biomass of Blue Mackerel in the West and East calculated from the 'best' estimate of each parameter were 56,228 t and 23,009 t, respectively (Ward and Rogers 2007). 'Minimum' and 'maximum' estimates ranged from 10,993 t to 293,456 t in the West and 7,565 t to 116,395 t in the East zone, respectively. The 'best' estimates of spawning biomass are conservative because the estimates of egg production on which they are based were obtained using the method of McGarvey and Kinloch (2001), which typically provides lower estimates than the internationally accepted method (i.e. linear version of exponential egg mortality model with application of a bias correction factor). In addition, there is evidence to suggest that spawning occurred outside the area surveyed in the West (i.e. in the western GAB). Spawning may also have occurred outside the survey area off eastern Australia. The survey conducted off eastern Australia in July 2004 may have also been conducted outside the peak spawning season. Much higher estimates of egg production (23.01–33.00 eggs per m^2 per day) were obtained in October 2003 compared to July 2004, however, spawning biomass could not be estimated for the 2003 survey due to limitations in the sampling design (non-parallel transects). If egg production estimates for October 2003 were used to calculate spawning biomass for July 2004, the best estimate of spawning biomass for eastern Australia would have been 77,648 t. Previous studies have shown that egg production and spawning area are key determinants of spawning biomass (Ward *et. al.* 2009). Sensitivity analyses conducted in the study suggest that estimates of spawning biomass were strongly affected by uncertainty in estimates of spawning fraction.

2.3.2.8 MSE

For Blue Mackerel East, the “best” DEPM estimate of spawning biomass was 13% of the model calculated estimate of virgin biomass. This is not an issue when investigating Tier 1 scenarios, as these are “relative” quantities determined as a percentage of the spawning biomass. The Tier 1 scenarios all reached equilibrium at around B_{60} by the end of the 30 year simulation period. The Tier 2 and Tier 3 results suggest that these harvest levels are conservative and sustainable, however, these should be treated with caution as these harvest quantities are “absolute” quantities and represent a much smaller proportion of the model calculated biomass than the DEPM estimate of biomass.

The results for Blue Mackerel West are similar to those for Blue Mackerel East. In this case the DEPM estimate of spawning biomass was 31% of the model calculated estimate of spawning biomass.

2.4 Summary and Conclusions

Preliminary historical DEPM assessments of Blue Mackerel provided a mid-range best estimate of spawning biomass of ~23,009 t in the East and a best estimate of ~56,000 t in the West. The MSE suggested that the spawning biomass was higher than the DEPM estimate in each region. The SPFRAG has noted that estimates of spawning biomass for blue mackerel for both East and West are likely to underestimate the actual spawning biomass.

Between 1997/98 and 2011/12, catches in the East ranged from ~250–1,000 t. In the West, catches increased rapidly after 2004 and reached ~2,000 t in 2008/09 with 135 t taken in 2011/12. Recent low catches appear to reflect low fishing activity rather than reductions in abundance. Reduced catches in the West since 2009/10 can also be attributed to a lack of targeted fishing for blue mackerel. Recent annual catches have been well below the maximum RBCs at Tier 2 for each zone suggesting the impacts on the spawning biomass are low. No fish sampled from catches in the West were below size at maturity; catches were dominated by 4 and 5 year olds. Woodhams *et al.* (2012) assigned Blue Mackerel in both zones to the categories of ‘not overfished’ and ‘not subjected to overfishing’. There is no evidence to suggest that recent low catches of Blue Mackerel in either zone are not sustainable. However, consideration should be given to conducting new DEPM assessments in each zone.

3 JACK MACKEREL AND YELLOWTAIL SCAD (*TRACHURUS SPP*.)

3.1 Introduction

3.1.1 Background to Fishery

A major purse seine fishery for small pelagic fishes developed off Tasmania in the mid–1980s, with catches peaking at over 40,000 t in 1986/87. The majority of the catch consisted of Jack Mackerel (*Trachurus declivis*), with a relatively small component of Redbait (*Emmelichthys nitidus*) and Blue Mackerel (*Scomber australasicus*) also taken as by-product. The fishery became the largest in Australia, by weight, before large reductions in catches in 1988/89 resulted in financial problems for the industrial fishery (Kailola *et al*. 1993; Pullen 1994a). Large-scale purse seine operations for Jack Mackerel continued through the 1990s. However large inter-annual fluctuations and an overall downward trend in production effectively resulted in purse seine operations ceasing in 2000. The majority of the catch was processed at plants in Triabunna (east coast of Tasmania) for fish meal and oil for aquaculture feed, with small quantities frozen for rock lobster bait, processed for human consumption or canned as pet food (Pullen 1994a).

In 2001/02, a 6-month fishing trial using a mid-water pair-trawl operation was established to target subsurface schools of Jack Mackerel to reduce dependence on the availability of surface schooling fish. A total catch of over 5,000 t was taken between December 2001 and April 2002, nearly 90% of which was Redbait. On the strength of this trial, a multipurpose 50 m mid-water trawler was brought to Tasmania to target small pelagic fish species with fishing operations commencing in late 2002. By the end of the 2002/03 fishing year more than 7,000 t of small pelagic fish was taken, with Redbait dominating the catch. More recent fishing for small pelagic fish by purse seine in Tasmanian State waters yielded 203 t of Jack Mackerel in 2007/08, 920 t in 2008/09 and 917 t in 2009/10 (Hartman and Lyle 2011).

A relatively small (300–500 t per annum) fishery for Yellowtail Scad (*Trachurus novaezelandiae*) exists in NSW where they are taken predominately in the Ocean Haul Fishery. Small quantities have also been landed in Western Australia (Kailola 1993).

3.1.2 Taxonomy

Jack Mackerel, *Trachurus declivis*, and Yellowtail Scad, *T. novaezelandiae,* belong to the family Carangidae of which there are 140 species representing 32 genera (Nelson 2006). Carangids are found worldwide with most species occurring in tropical waters. There are 65 species in Australia, of which 8 species from four genera inhabit southern temperate waters (Gomon *et al.* 2008). The genus *Trachurus* contains 13 species with three found in Australia, namely *T. declivis, T. murphyi* and *T. novaezelandiae*.

3.1.3 Distribution

Jack Mackerel are widely distributed throughout coastal waters of southern Australia and New Zealand. In Australia, they are distributed from Shark Bay in Western Australia, to Wide Bay in Queensland, including the waters around Tasmania (Gomon *et al.* 2008). They are found down to a maximum depth of 500 m, but more commonly over the continental shelf to 200 m (Pullen 1994a). Yellowtail Scad have a similar distribution to Jack Mackerel although they penetrate slightly further to the north on each side of the continent and rarely reach Tasmania (Kailola 1993; Gomon *et al.* 2008).

3.1.4 Stock Structure

There is some evidence to suggest that at least two populations of Jack Mackerel occur within Australian waters, with a third population occurring in New Zealand. Analysis of morphometric measurements and meristic counts showed a significant difference between east Australian fish and those from the Great Australian Bight (GAB) (Lindholm and Maxwell 1988). Genetic studies have found no significant differences between southern NSW and eastern Tasmanian fish (Smolenski *et al.* 1994) but distinct differences between GAB and New Zealand fish (Richardson 1982). In an extensive review of available biological, environmental and fishery data Bulman *et al.* (2008) concluded that Jack Mackerel from eastern Australia and eastern Tasmania were likely to be a separate sub-population to fish from west of Tasmania, including the GAB and Western Australia. Little is known of the stock structure of Yellowtail Scad in Australian waters.

3.1.5 Movement

No specific studies have focused on the movement of Jack Mackerel or Yellowtail Scad. However, a correlation between size and depth is evident, with smaller fish generally found inshore and larger fish offshore (Shuntov 1969; Kailola 1993; Stevens *et al.* 1984; Pullen 1994). Such size-dependent distribution suggests offshore movement with increasing size.

3.1.6 Food and Feeding

Jack Mackerel feed primarily on aquatic crustaceans, particularly euphasiids (krill) and copepods (Shuntov 1969; Stevens *et al.* 1984; McLeod 2005; Bulman *et al.*

2008). Krill, in particular *Nyctiphanes australis*, are the most common dietary item for Jack Mackerel throughout its distribution, and account for 44% of diet in fish from eastern Tasmania (Webb 1976; Williams and Pullen 1993; McLeod 2005). Fish from deepwater also consume mesopelagic fish (Maxwell 1979; Blaber and Bulman 1987). In addition, Jack Mackerel consume a variety of other prey items in minor quantities including ostrocods, gastropods, amphipods, isopods, polycheates and echinoderms (Stevens *et al.* 1984; Blaber and Bulman 1987; McLeod 2005). Dietary composition has also been shown to vary seasonally (Bulman *et al.* 2008).

Studies in the GAB found that Jack Mackerel generally feed during the day with fish in offshore waters feeding mostly on krill and fish in inshore waters consuming more copepods (Shuntov 1969; Stevens *et al.* 1984). Prey size has been shown to be dependent on fish size, with larger prey items taken by larger fish (Stevens *et al.* 1984).

3.1.7 Age, Growth and Size

Jack Mackerel reach a maximum of 470 mm in length, 1 kg in weight and 17 years of age (Last *et al.* 1983; Williams and Pullen 1986; Lyle *et al.* 2000; Browne 2005). Multiple studies have investigated the age and growth of Jack Mackerel: Webb and Grant (1979), Stevens and Hausfeld (1982) and Jordan (1994) using whole otoliths, and Lyle *et al.* (2000) and Browne (2005) using sectioned otoliths. Lyle *et al.* (2000) validated the aging protocol based on marginal increment analysis. Jack Mackerel grow quickly at a young age, reaching 270 mm in the first 4 years and obtain 335 mm by age 10 years off Tasmania, with no significant difference in growth between males and females (Lyle *et al.* 2000). Yellowtail Scad grow quickly to reach ~200 mm at 2–4 years of age (Stewart and Ferrell 2001), maximum size is about 330 mm total length (Kailola 1993) with the oldest recorded individual being 14 years old (Stewart and Ferrell 2001).

3.1.8 Reproduction

Jack Mackerel are serial spawners, although spawning frequency has not been determined in Australian waters (Marshall *et al.* 1993; Neira 2011). Mean batch fecundity was estimated to be ~63,000 eggs for females from eastern Tasmania (Neira 2011). Females have been shown to reach 50% sexual maturity at 315 mm (Marshall *et al.* 1993). Spawning has been known to occur in spring in NSW (Maxwell 1979; Keane 2009) and during summer off Tasmania and in the GAB (Stevens *et al.* 1984; Marshall *et al.* 1993; Jordan *et al.* 1995). Mean female GSI values for eastern Tasmanian fish increase substantially in November and stay high until January, before declining in February (Williams *et al.* 1986). Backdated birthdates based on otolith microstructure of larval fish indicated spawning to occur between mid December and mid February (Jordan 1994). Furthermore they indicate spawning to occur in a semi-lunar cycle with peaks associated with both full and new moons.

The reproductive biology of Yellowtail Scad is not fully understood for the Australian population (Neira 2009). Mean batch fecundity was estimated to be ~39,000 eggs based on published eggs.g^{-1} values applied to mean female weight from commercial catch data (Neira 2009). Female and male Yellowtail Scad reach sexual maturity at 200 mm and 220 mm fork length (FL), respectively (Kailola 1993).

3.1.9 Early Life History and Recruitment

Jack Mackerel eggs are positively buoyant and 0.97–1.03 mm in diameter (Neira 2011). Larvae have been described by Trnski (1998). Larvae have been caught off southern NSW during spring and eastern Tasmania and in Bass Strait and in the GAB predominantly during summer (Stevens *et al.* 1984; Neira 2005; Keane 2009). Yellowtail Scad eggs are morphologically similar to Jack Mackerel eggs but slightly smaller (0.78–0.88 mm, Neira 2009)

3.1.10 Stock Assessment

During the late 1980s and early 1990s, considerable research effort was directed at describing the fisheries biology of Jack Mackerel. Projects were initiated to (a) evaluate tools for assessment of the Jack Mackerel stocks; (b) describe factors contributing to inter-annual variability in the availability of Jack Mackerel; and (c) collect information on the early life history and reproductive biology of the species (Jordan *et al.* 1992; 1995). Research outputs included greater understanding of interactions between local oceanography and the availability of surface schools of Jack Mackerel (Harris *et al.* 1992; Williams and Pullen 1993), and data on the reproductive biology and early life history of Jack Mackerel (Harris *et al.* 1992; Young and Davis 1992; Marshall *et al.* 1993; Williams and Pullen 1993; Jordan 1994; Jordan *et al.* 1995). However, no successful method of assessing the size of the Jack Mackerel resource was developed, despite attempts to use a combination of aerial surveys of surface schooling fish, and hydroacoustic surveys of surface and sub-surface schools on the shelf break (Jordan *et al.* 1992).

The DEPM was applied to this species in 2011 using samples collected off south-eastern Australia in 2002 during a survey targeting Blue Mackerel eggs (Neira 2011). Adult parameters for the DEPM were derived from Tasmanian trawl samples and published data.

3.1.11 Management

This fishery has changed dramatically since the commencement of large scale fishing operations in the mid–1980s, from a purse seine fishery for Jack Mackerel to a mid-water trawl fishery primarily targeting Redbait, with Jack Mackerel an important by-product. Between the late 1980s and prior to the implementation of the Commonwealth Small Pelagic Fishery Management Plan in 2009, the Tasmanian component of the fishery (Zone A: north-eastern Tasmania to central western Tasmania) was managed using a combination of input and output controls, principal among these being a TAC. A combined species TAC for Zone A was initially set at 42,000 t in 1988/89 and was based on the highest annual catch from the purse seine fishery (Jordan *et al.* 1992). The TAC for Zone A was decreased to 34,000 t in 2002/03 with the renewed interest in small pelagic fish and commencement of mid-water trawl operations. Despite catches not approaching this level, the TAC was applied in subsequent fishing seasons up until 2008/09 at which time the SPF was split into East and West zones and, under the SPF harvest strategy framework (AFMA 2008), species and zone specific TACs were established. For the 2011/12 season, the recommended TAC for Jack Mackerel was 4,600 t in the East and 5,000 t in the West. Both East and West zones are currently managed at the Tier 2 level. The DEPM spawning biomass estimates provided by Neira (2011) were used to set the Tier 2 maximum RBC for Jack Mackerel East at 10,600 t (AFMA 2008).

Yellowtail Scad is classed as a permitted by-catch species in the SPF.

3.2 Methods

3.2.1 Fishery Statistics

Commercial operators participating in the Zone A Jack Mackerel purse seine fishery were required to complete logbooks recording catch and effort from the inception of the fishery (1984). The initial logbook comprised a shot by shot record of fishing operations, including species composition. This was replaced from the 1990/91 fishing year with a trip catch return, in which catch composition was not routinely reported, just total landings of small pelagic fish. Trawl operations since 2001/02 have been reported in the South East Trawl Fishery logbook, providing a shot by shot record of catch and effort, including catch composition. More recently, purse seine operations targeting small pelagic fish have resumed in Tasmanian State waters and shot by shot catch and effort are recorded in the Tasmanian general fishery logbook.

3.2.2 Biological Information

No biological data were made available for Jack Mackerel during the 2011/12 financial year. Fishery dependent length frequency and biological data for Jack Mackerel were collected between 1984 and 1993 as part of a monitoring program of the Jack Mackerel purse seine fishery. Some biological information was also collected from samples of Jack Mackerel collected from demersal research trawling conducted by CSIRO and the relevant Tasmanian fisheries agency between 1985 and 1990. Between 1994 and 2001, the level of catch sampling of the purse seine fishery was limited.

Collection of biological data during the 2001/02 pair-trawl fishing trials was undertaken by AFMA observers on a small proportion of trips, so data are limited and may not be representative of the catch. Following the commencement of mid-water trawl operations in 2002, the Tasmanian Aquaculture and Fisheries Institute (TAFI) commenced an intensive biological monitoring program that continued to 2006. AFMA also provided observer coverage of mid-water trawl operations, with additional length frequency data collected from 2002 to 2008.

Purse seine operations for small pelagic fish resumed in Tasmanian State waters during 2008/09, with Redbait and Jack Mackerel the main species targeted. Catch sampling of mid-water trawl and purse seine operations adjacent to Tasmania was implemented in 2009 as part of the SPF monitoring program under the SPF Harvest Strategy framework (AFMA 2008).

Biological data were collected from individual specimens and included FL (to the nearest millimetre), total weight (to the nearest gram), sex, gonad developmental stage (following the macroscopic staging criteria described in Marshall *et al.* 1993) and gonad weight (to the nearest 0.1g). Otoliths were also extracted and used for age estimation and growth modelling (Williams *et al.* 1987).

Commercial logbook information, length frequency and biological data collected over the period 1984–2012 were available for the present review. Age growth and reproductive data for Jack Mackerel were available from previous studies by Jordan *et al.* (1992), Lyle *et al.* (2000) and Browne (2005). In addition, as part of the present assessment, specimens from 2009/10 mid-water trawl and purse seine fishing operations were analysed to provide recent size and age composition estimates of the catch. No biological samples were collected in 2010/11 or 2011/12 due to limited activity in the fishery.

3.2.3 Biomass Estimates and MSE

A preliminary biomass estimate for Jack Mackerel was obtained for the East using samples collected during a study in 2002 (Neira 2011).

3.3 Results

3.3.1 Fishery Statistics East / West

3.3.1.1 Number of vessels

The number of vessels that reported landings of Jack Mackerel in the East was slightly greater than in the previous year, but considerably less than the long-term average (Fig. 3.1). The majority of vessels operating within this zone were from NSW and Victoria with comparatively low levels of fishing activity reported from Tasmania (<5 vessels in 2011/12). Relatively few vessels reported landings of Jack Mackerel in the West, with those doing so operating exclusively within South Australian waters (Fig. 3.2). Overall, the number of vessels operating within both zones appears to demonstrate a general decrease over the last 15 years.

The number of vessels reporting landings of Yellowtail Scad increased dramatically in 2011/12 (>940) with the majority of these operating in NSW waters (Fig. 3.3).

3.3.1.2 Annual Patterns-catch, effort & catch-per unit effort

Combined catches of Jack Mackerel for the East declined from >9,000 t in 1997/98 to ~100 t in 2000/01 (Fig. 3.4), landings then increased to >2,000 t between 2002/03 and 2004/05, but then declined again to 43 t during 2010/11 and 58 t in 2011/12. The absence of data describing vessel days (NSW, Tasmania) means that no estimates can be derived for fishing effort or CPUE during the 2011/12 fishing year. Historically, annual estimates of effort have trended downwards from a peak of ~1,100 vessel days in 1998/99 to almost no effort in 2011/12 (Fig. 3.4; <11 days). CPUE has fluctuated considerably over the same period (Fig. 3.5), possibly because of changes in the type of gear employed and vessels used in this fishery.

Jack Mackerel catches in the West have historically been lower than those in the East (Fig. 3.6). Annual catches have exceeded 330 t on two occasions, 2005/06 and 2006/07, all other non-confidential catches have been <180 t (Fig. 3.6). Fluctuations in catches have not reflected relative changes in annual fishing effort (Fig. 3.6). From 1997/98–2004/05, catches rates were <2 t per vessel day, however, over the last six years non-confidential catch rates have consistently exceeded 4 t per vessel day (Fig. 3.7).

Yellowtail Scad catches in the East were ~500 t in 1997/98 and gradually trended down to 250 t in 2009/10, before increasing to ~450 t in 2010/11 (Fig. 3.8). This trend has continued in 2011/12 with catches approaching 500 t (Fig. 3.8). Whilst effort data are unavailable for 2011/12, the trend of increasing catch appears to contrast the comparatively low level of effort over the last few years (particularly the <3,000 vessel days observed for 2010/11) which is considerably lower than the historical average of ~7,000 vessel days during 1997/98 to 2008/09 (Fig.3.8). Changes to the efficiency of Yellowtail Scad fishing operations in the East are brought out by the substantial increase in CPUE which rose from a long-term average of ~0.5 t per vessel day between 1997/98 and 2009/10 to >1.5 t per vessel day in 2010/11 (Fig. 3.9). No Yellowtail Scad were reported from the West.

3.3.1.3 Intra-annual Patterns-catch and effort

Presentation and interpretation of intra-annual data for Jack Mackerel catches from the East were affected by confidentiality issues arising from the small number of vessels participating in the fishery. Between 1997/98 and 1999/2000, most of the Jack Mackerel catch in the East was taken during the summer months (Fig. 3.10). No intra-annual data were presented for Jack Mackerel from the West due to confidentiality issues. No consistent intra-annual patterns were evident in the Yellowtail Scad catches (East), although in some years an increase in catches was evident in summer and early autumn (Fig. 3.11).

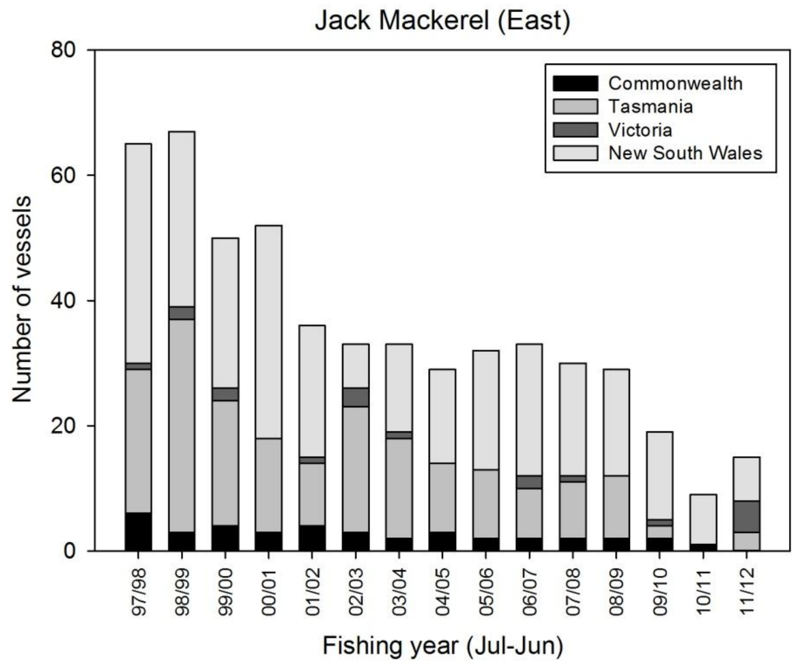

Figure 3.1 Number of vessels which landed Jack Mackerel in the East, from each of the participating management jurisdictions.

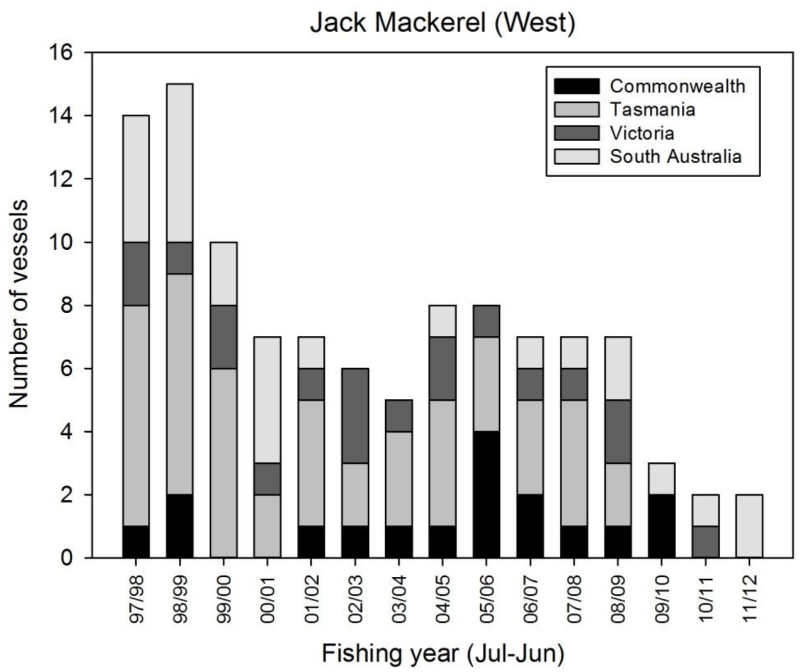

Figure 3.2 Number of vessels which landed Jack Mackerel in the West, from each of the participating management jurisdictions.

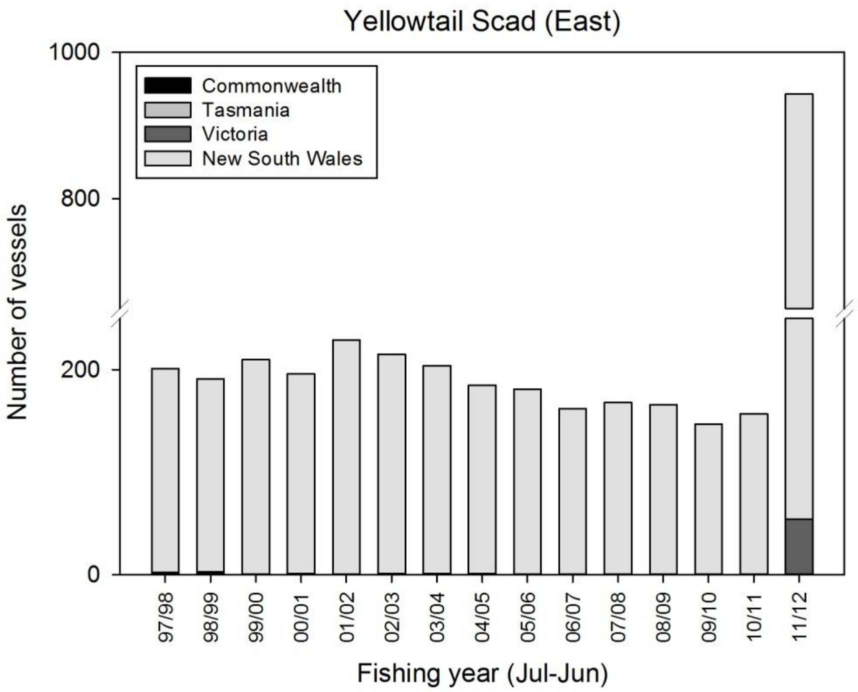

Figure 3.3 Number of vessels which landed Yellowtail Scad in the East, from each of the participating management jurisdictions.

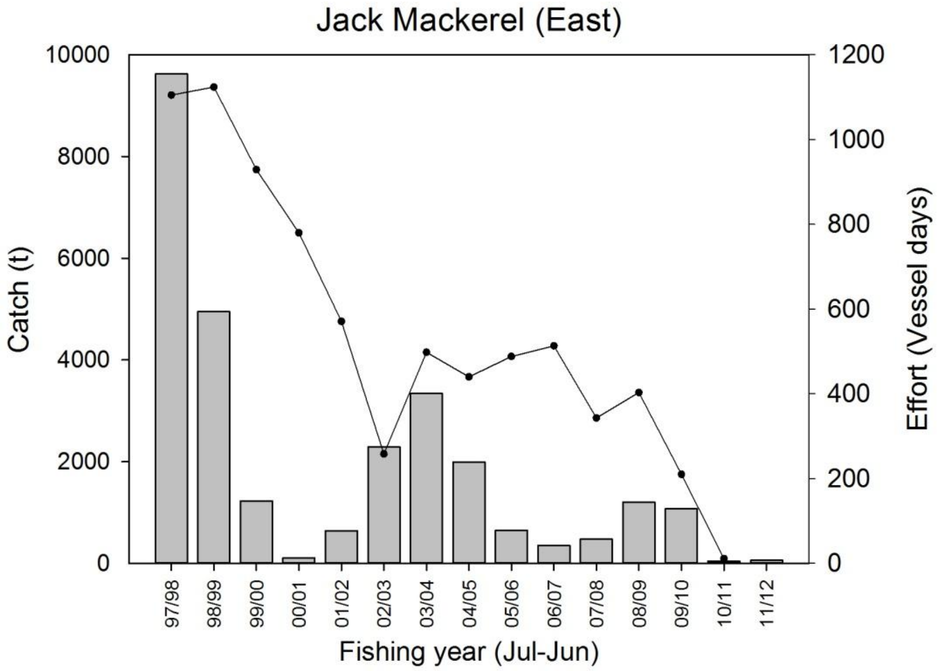

Figure 3.4 Total landed catch (t, bars) and effort (vessel days, line) for Jack Mackerel in the East during financial years over the period 1997/98–2011/12.

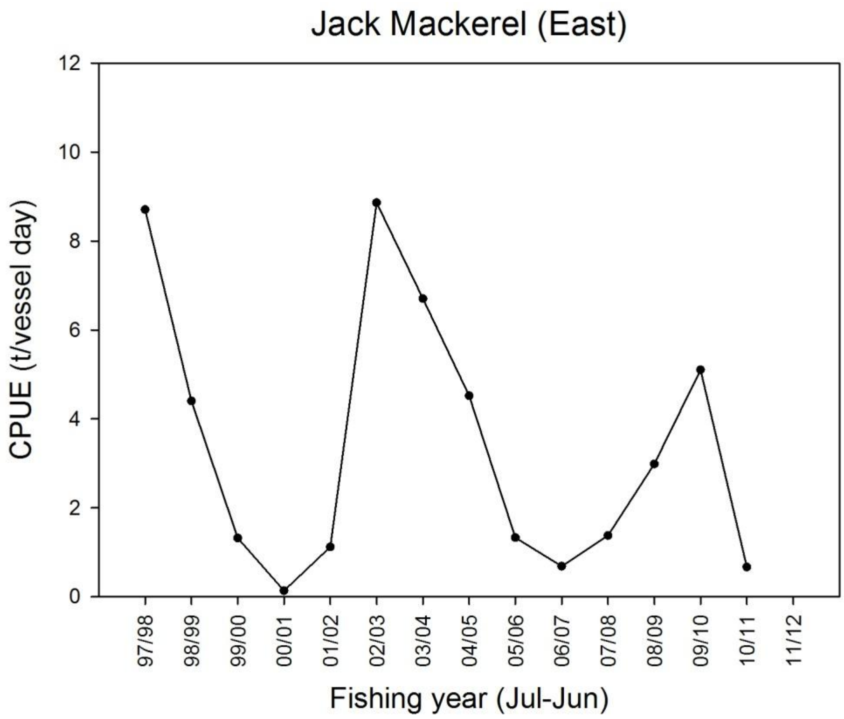

Figure 3.5 CPUE (t per vessel day) for Jack Mackerel in the East during financial years over the period 1997/98–2011/12.

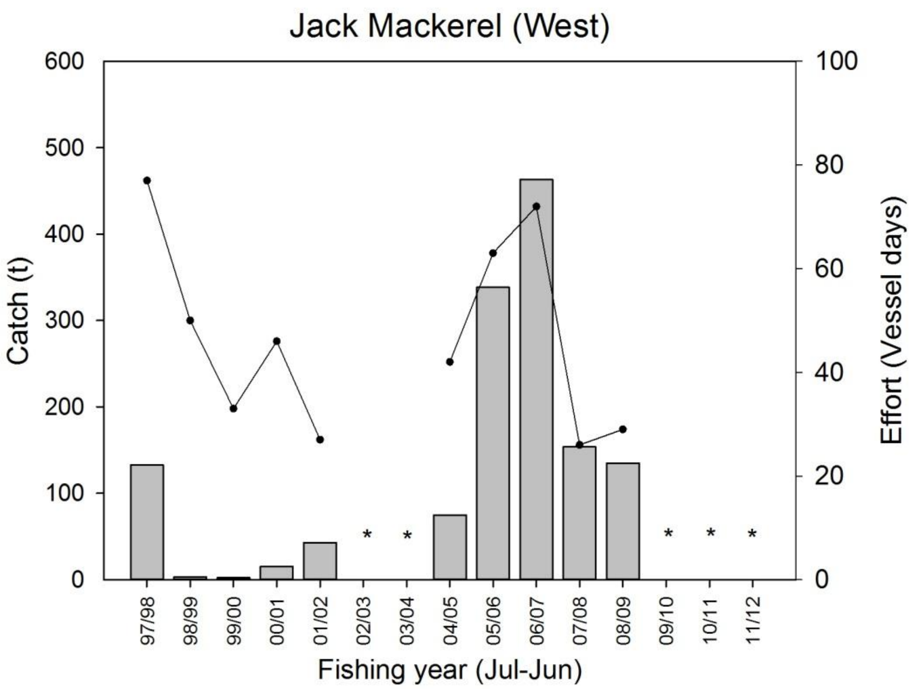

Figure 3.6 Total landed catch (t, bars) and effort (vessel days, line) for Jack Mackerel in the West during financial years over the period 1997/98–2011/12. The low number of vessels within this region means that some catch and effort data are confidential (*).

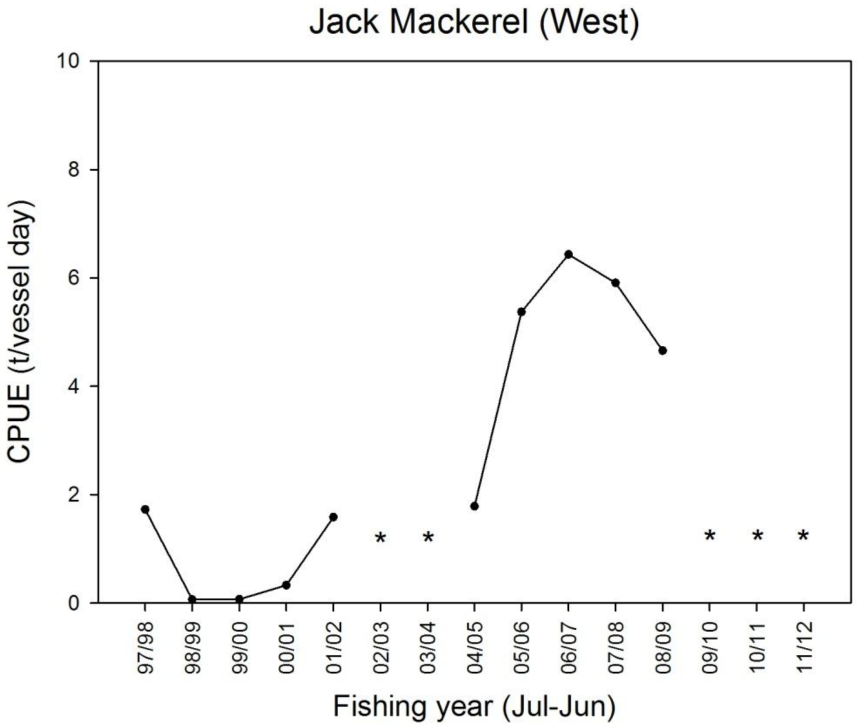

Figure 3.7 CPUE (t per vessel day) for Jack Mackerel in the West during financial years over the period 1997/98–2011/12. The low number of vessels within this region means that some data are confidential (*).

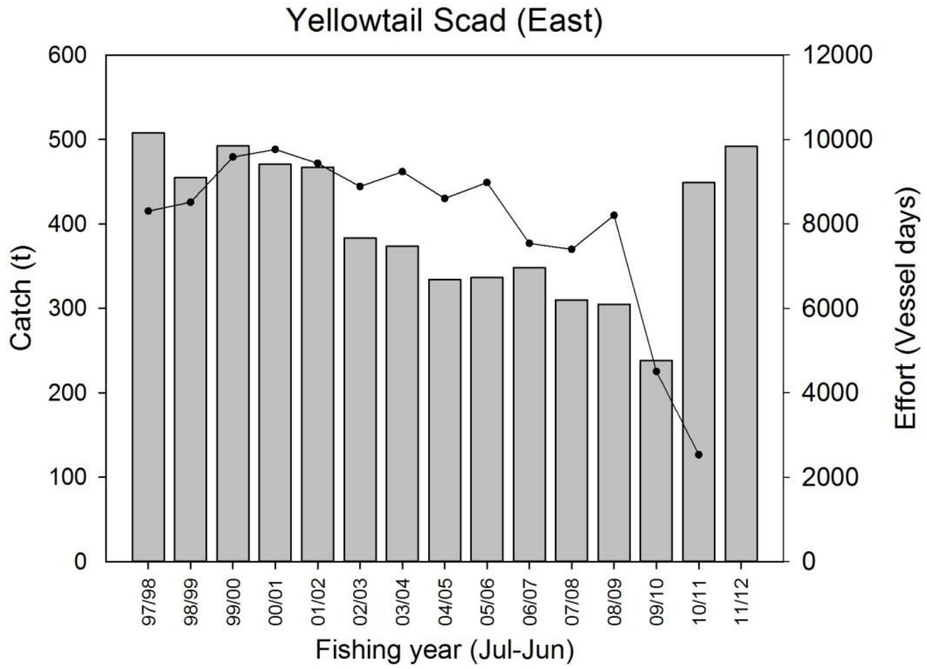

Figure 3.8 Total landed catch (t, bars) and effort (vessel days, line) for Yellowtail Scad in the East during financial years over the period 1997/98–2011/12.

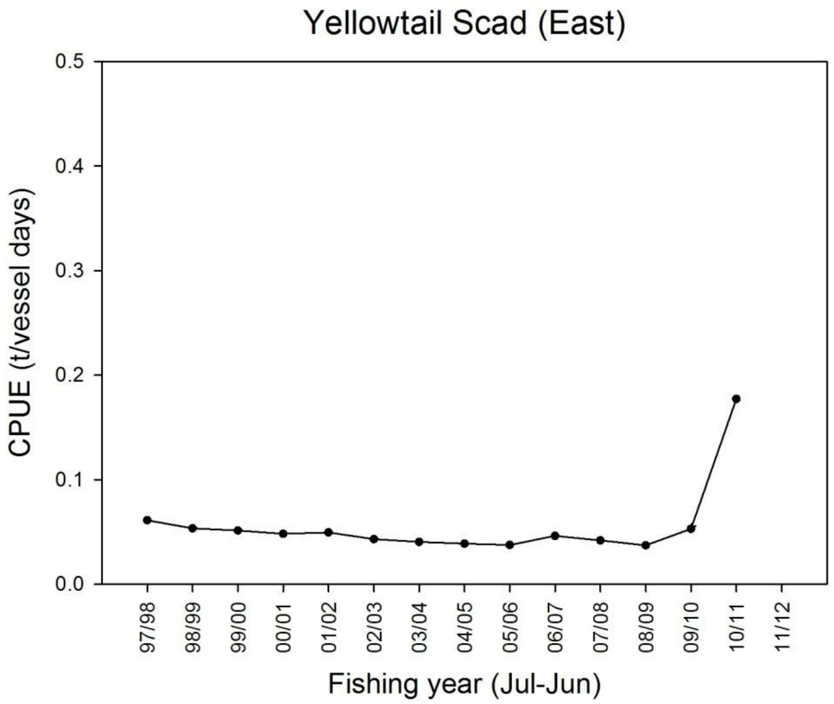

Figure 3.9 CPUE (t per vessel day) for Yellowtail Scad in the East during financial years over the period 1997/98–2010/11. The absence of effort data precluded the calculation of this statistic for 2011/12.

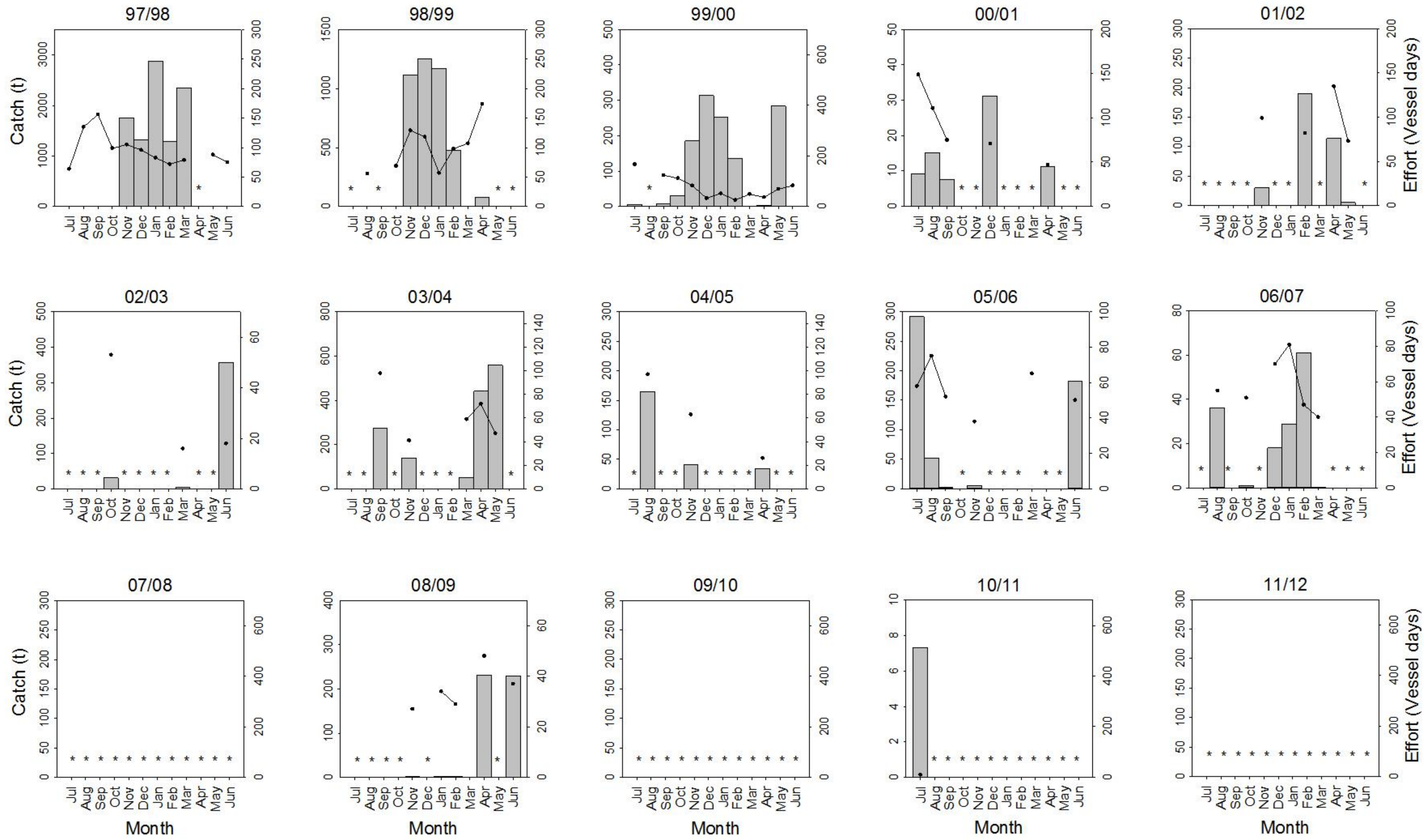

Figure 3.10 Intra-annual patterns of catch (bars) and effort (line) for Jack Mackerel in the East for the period from 1997/98 to 2011/12. (*) indicates data confidentiality, where <5 license holders report landings from individual month.

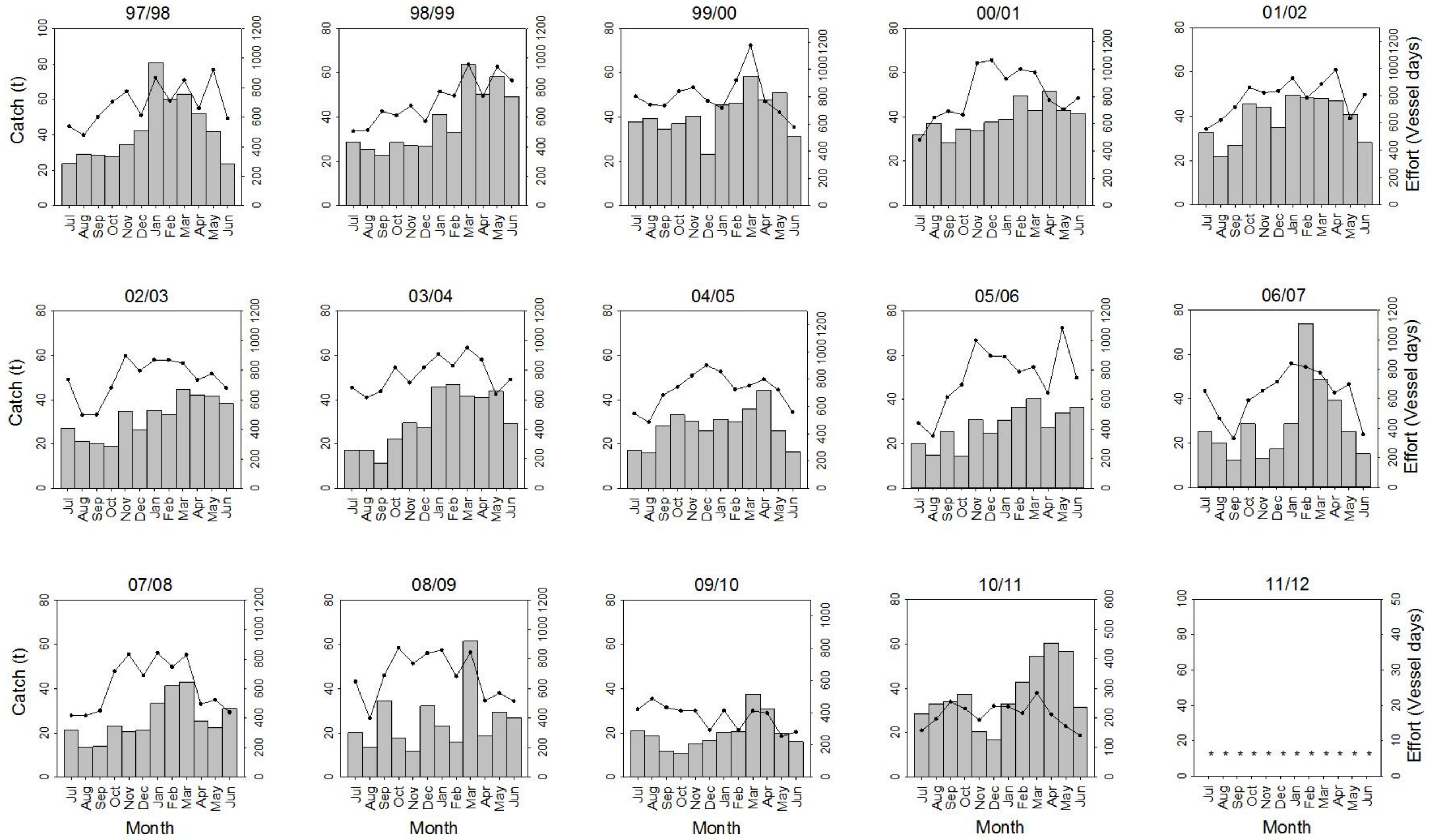

Figure 3.11 Intra-annual patterns of catch (bar) and effort (line) for Yellowtail Scad in the East for the period from 1997/98 to 2011/12. (*) indicates data confidentiality, where <5 license holders report landings from individual month.

3.3.2 Biological Information

3.3.2.1 Size Structure

The purse seine fishery: 1984/85–2000/01

Jack Mackerel caught in the purse seine fishery between 1984 and 1996 off eastern Tasmania were mostly 210–350 mm FL, with individuals up to 440 mm recorded (Fig. 3.12). In the first year of the fishery the catch comprised fish between 240 and 360 mm with a bimodal distribution. From 1985/86 to 1988/89, catches were dominated by a single mode, with most fish in the 250–350 mm size range and evidence for a slight shift to larger fish. A second cohort of small fish (<250 mm) was first evident in 1988/89 and by 1989/90 the size distribution was bimodal, with peaks at 240 mm and 320–330 mm. Bimodal size structure was evident in the following three years, the position and relative heights of the modes varying between years. The size compositions for 1993/94 to 1995/96 were unimodal, and showed evidence of a general shift to larger fish.

Mid-water trawl fishery: 2001/02–2005/06

Jack Mackerel caught by mid-water trawl operations off eastern Tasmania after 2001 were considerably smaller than those caught by the earlier purse seine operations, with specimens mostly between 200 and 300 mm (Fig. 3.13, 3.14).

East coast catches were characterised by an increase in modal length, from 240 to 270 mm between 2002/03 and 2004/05, and only a small proportion of the catch made up of fish larger than 300 mm (Fig. 3.13). By contrast, catches from south-western Tasmania were mostly between 250 and 370 mm, with an overall modal length of 290 mm (Fig. 3.14).

Mid-water trawl and purse seine operations: 2009/10–2010/11

Overall 1,862 Jack Mackerel from 21 mid-water trawl and purse seine catches were sampled between July 2009 and June 2010; all but one based on catches taken off eastern Tasmania (Table 3.1).

The size composition of east coast mid-water trawl and purse seine catches were similar, dominated by 180–240 mm fish (Fig. 3.15). Overall, these were smaller than those taken by mid-water trawl during the early 2000s and were small in comparison with the purse seine catches of the 1980s and 1990s. The single mid-water trawl catch sample from south-western Tasmania was comprised of fish of similar size to catches from eastern Tasmania (Table 3.1), being substantially smaller than fish taken by mid-water trawl during the early 2000s.

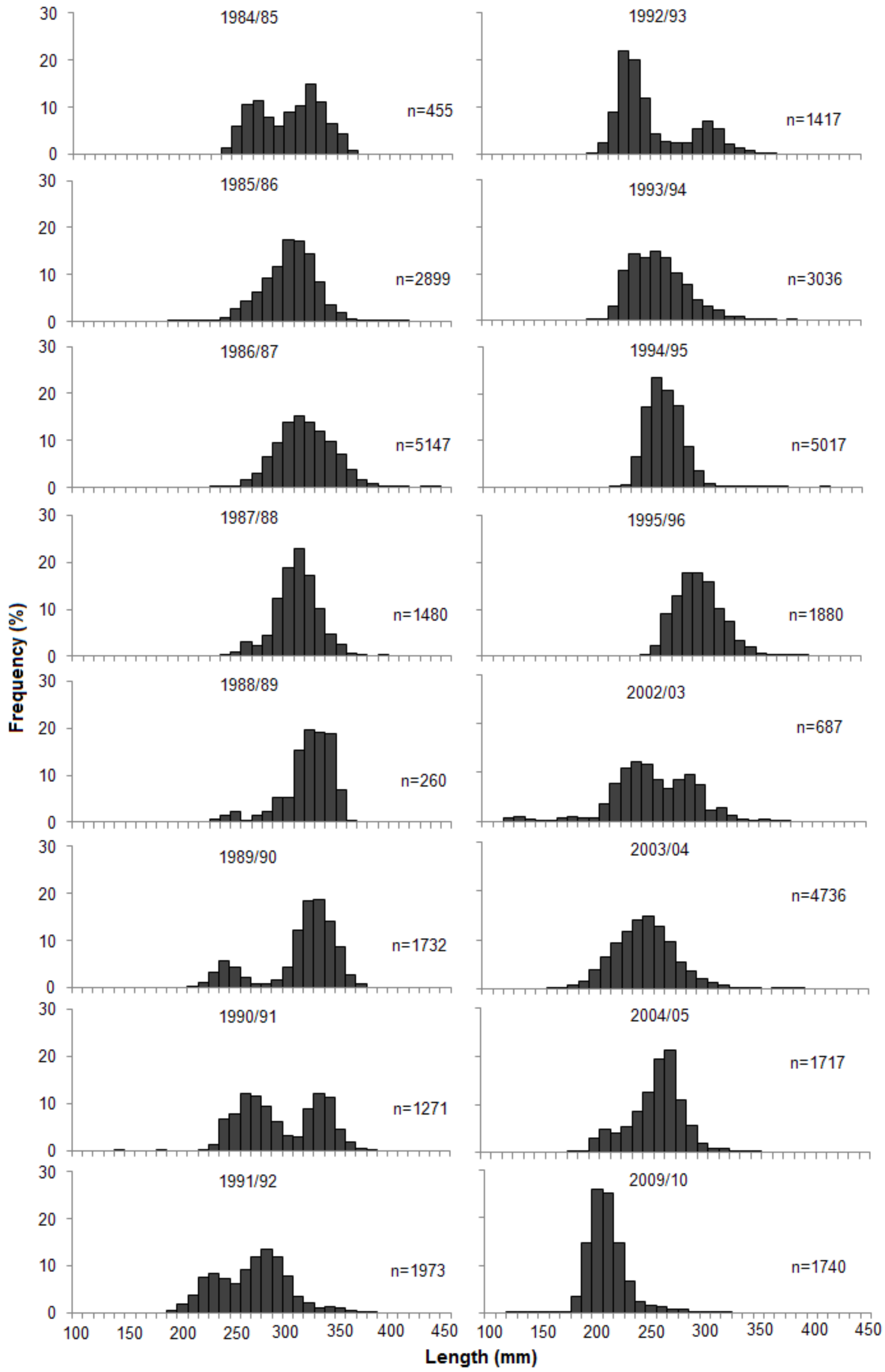

Figure 3.12 Length frequency distributions of Jack Mackerel caught in the SPF by purse seine (1984/85–1995/96), mid-water trawl (2002/03–2005/06) and both fishing methods combined (2009/10) off eastern Tasmania between 1984/85 and 2010/11. No data were available between 1997/98 and 2001/02. n is sample size.

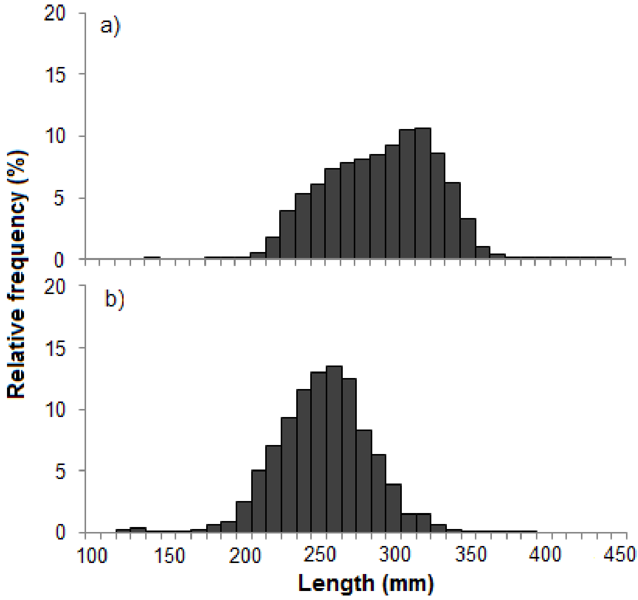

Figure 3.13 Year-weighted length frequency distributions of Jack Mackerel caught in the SPF off eastern Tasmania from (a) purse seine operations (1984/85–1996/97), and (b) mid-water trawl operations (2002/03–2005/06).

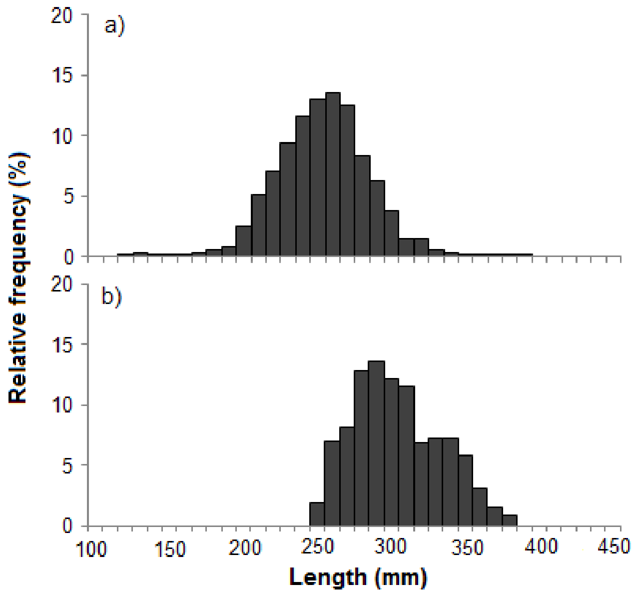

Figure 3.14 Year-weighted length frequency distributions of Jack Mackerel caught in the SPF off (a) eastern and (b) south-western Tasmania from mid-water trawl operations between 2002/03 and 2005/06.

Table 3.1 Summary of shots sampled in the SPF off Tasmania for Jack Mackerel length-frequency data during 2009/10–2010/11. The number of individuals (n) in length-frequency distributions is indicated with the size range and mode.

Sampling month	No. of landings	Location	Gear type	n	Size range (mm)	Mode (mm)
Jul–09	1	South-west	Midwater trawl	132	160–220	190
Aug–09	3	East coast	Midwater trawl	248	150–290	200
Sep–09	2	East coast	Midwater trawl	70	210–250	220
Oct–09	1	East coast	Purse seine	204	160–230	200
Dec–09	1	East coast	Purse seine	87	190–320	220
Jan–09	1	East coast	Purse seine	62	200–250	220
Feb–10	6	East coast	Purse seine	602	170–320	210
Mar–10	2	East coast	Purse seine	181	120–290	210
May–10	1	East coast	Purse seine	48	140–250	200
Jun–10	3	East coast	Purse seine	228	150–300	210

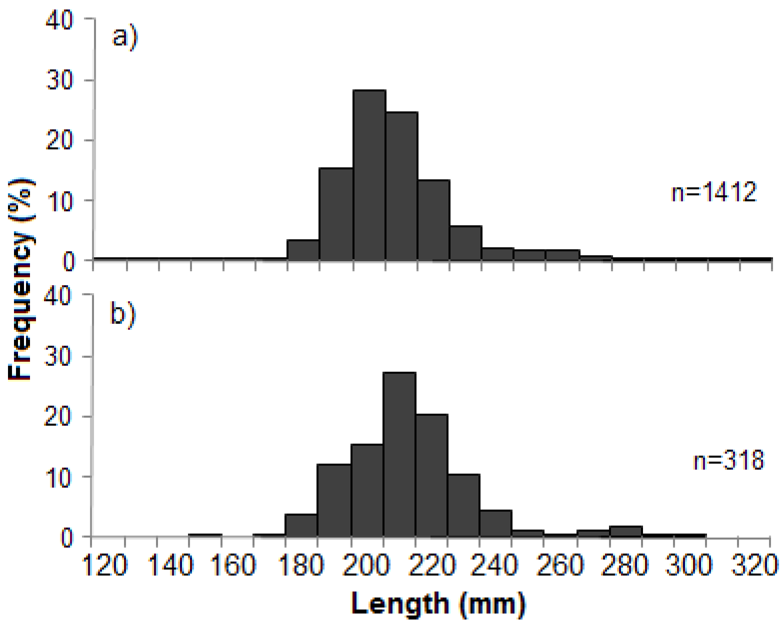

Figure 3.15 Length frequency distribution of Jack Mackerel caught in the SPF off eastern Tasmania by (a) purse seine and (b) mid-water trawl operations during 2009/10. n is sample size.

3.3.3 Age and Growth

Growth of male and female Jack Mackerel from eastern Tasmania was described using the von Bertalanffy growth function (VBGF) (Table 3.2, Fig. 3.16). Growth is rapid within the first few years of life, with individuals reaching a mean length in excess of 230 mm FL in the first three years, slowing thereafter. Maximum assigned ages for females and males were 15 and 16 years, respectively.

Table 3.2 Summary of VBGF parameters of Jack Mackerel off eastern Tasmania. Pooled data includes males, females and unsexed/unknown individuals.

		VB parameters		
	n	**L_∞**	**K**	**t_0**
Male	534	364.0	0.27	–0.92
Female	763	360.3	0.29	–0.63
Pooled	2143	362.8	0.29	–0.81

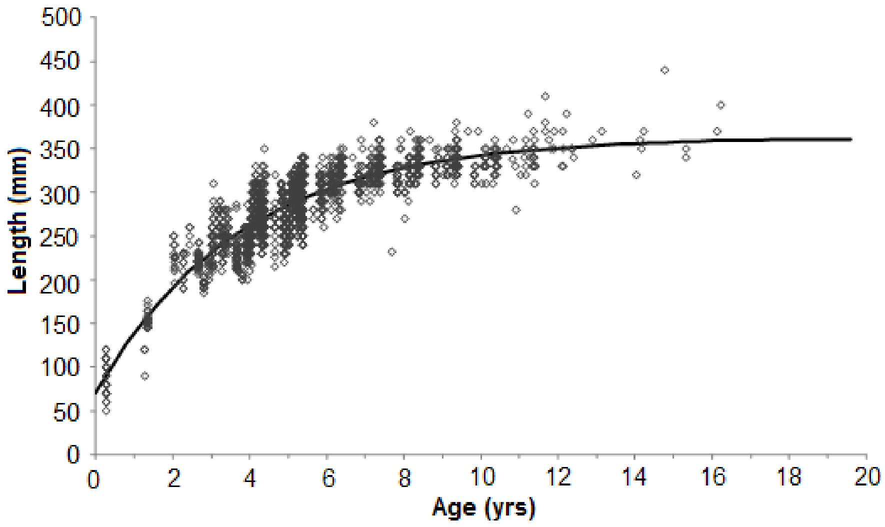

Figure 3.16 Length at age data for Jack Mackerel from eastern Tasmania. The black line represents the VB growth function.

3.3.4 Age Structure

3.3.4.1 The purse seine fishery: 1984/85–2000/01

The age structure of Jack Mackerel caught in Zone A of the SPF was estimated using age length keys based on age data pooled from the 1985/86, 1989/90, 1993/94 and 1994/95 fishing years. Jack Mackerel taken by the purse seine fishery were generally 3–10 years old (Fig. 3.17). Catches between 1984/85 and 1990/91 were dominated by 4 and 5 year olds with age classes up to about 9 years also well represented. Between 1991/92 and 1994/95, few fish older than 5 years were taken, with 3–5 year olds the dominant age groups. The 1995/96 age structure was similar to that of the mid 1980s suggesting that the relative scarcity of older fish evident in the intervening years may not have been solely due to impact of fishing on population age structure. However, it should be noted that the application of a pooled age length key rather than annual age structure appears to have had a smoothing effect on age compositions, in particular in terms of representation of the older age groups.

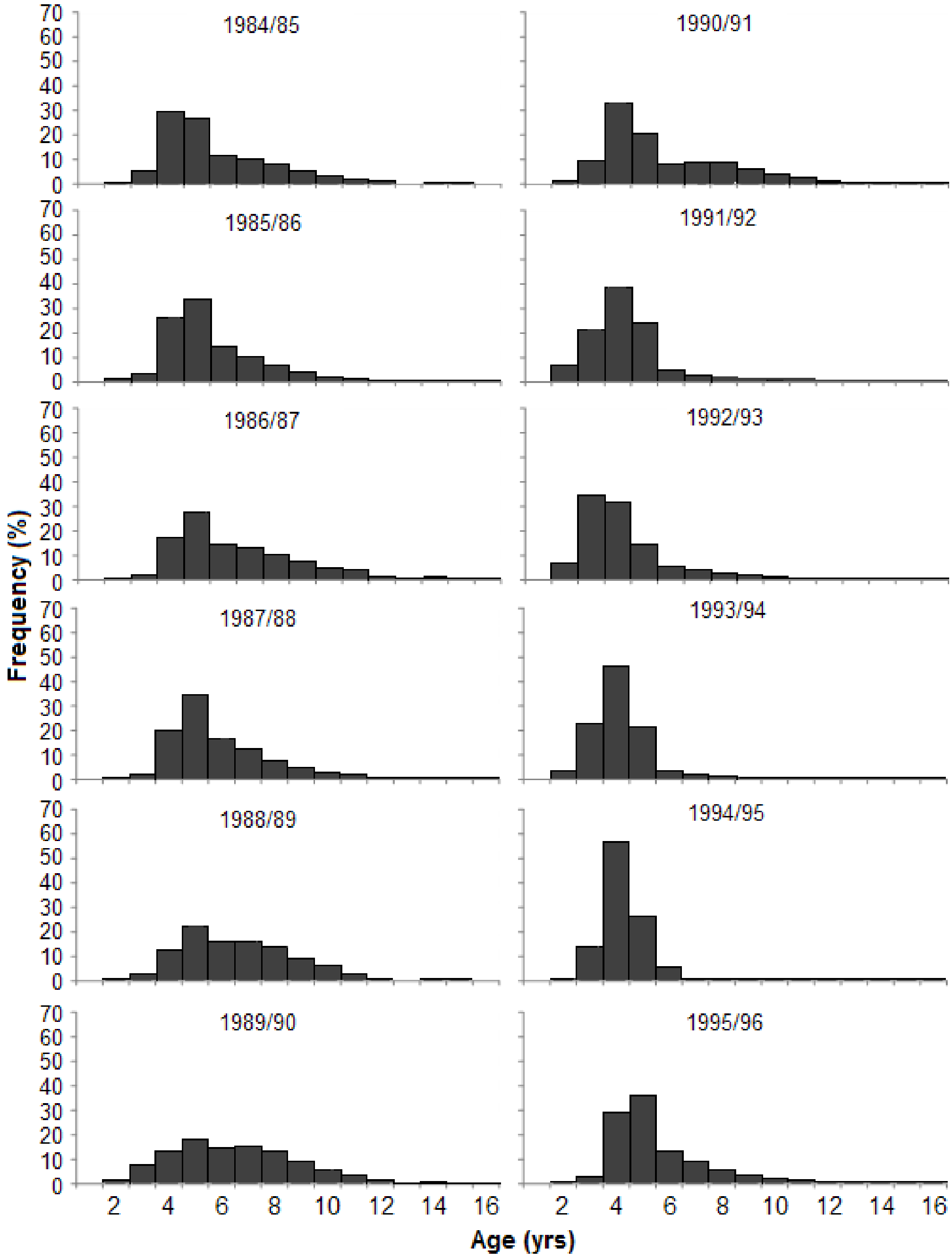

Figure 3.17. Age structure of Jack Mackerel from catch sampling from eastern Tasmania between 1984/85 and 1995/96.

3.3.4.2 Mid-water trawl fishery: 2001/02–2008/09

Jack Mackerel mid-water trawl catches off eastern Tasmanian between 2001/02 and 2004/05 mainly comprised fish aged 2–5 years old, with a modal age of 3–4 years (Fig. 3.18). By contrast, the age structure of catches from south-western Tasmania were characterised by a higher proportion of fish older than 5 years, and a mode at 4–5 years in each of the years sampled.

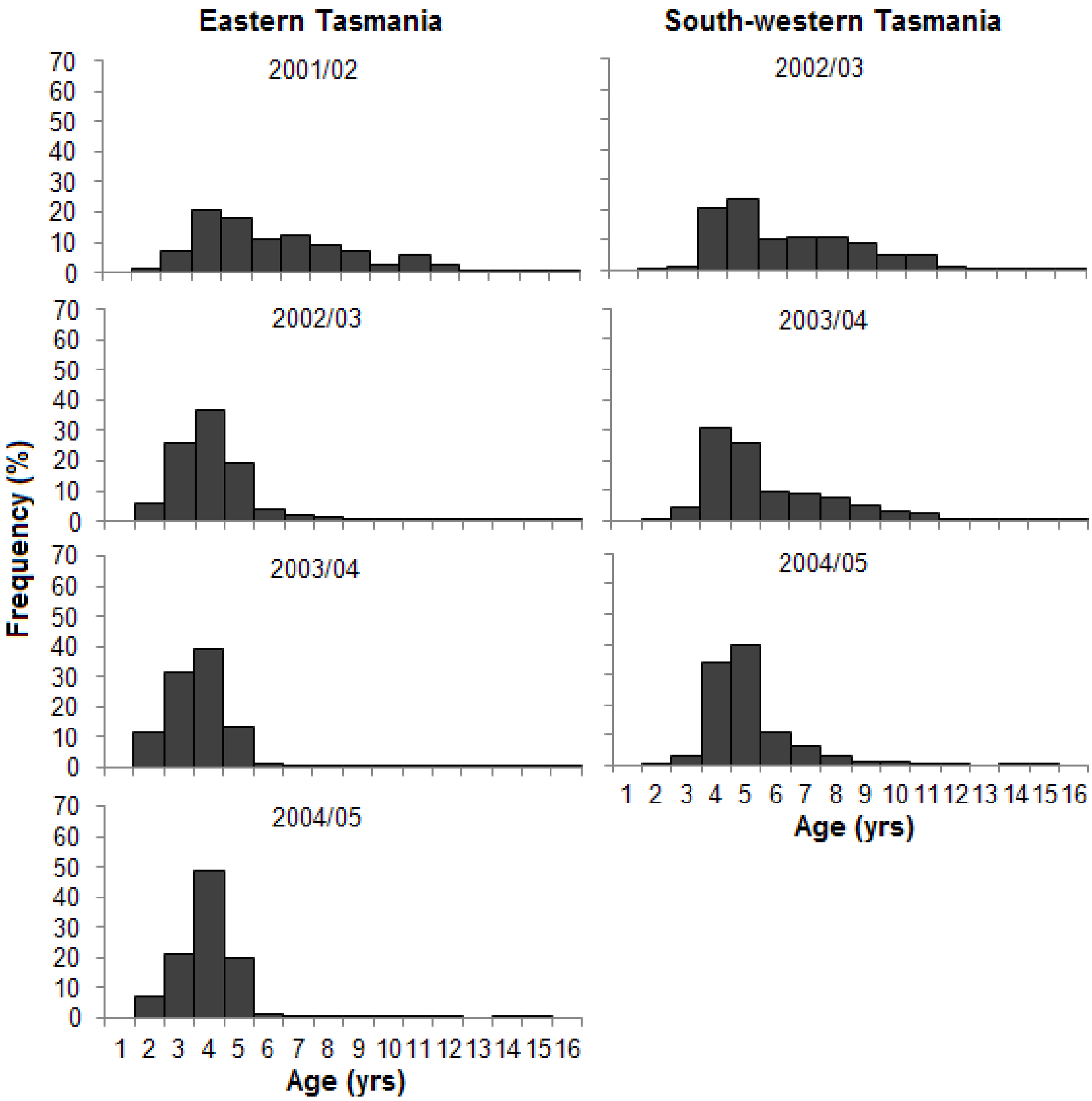

Figure 3.18 Age structure of Jack Mackerel catch samples from eastern and south-western Tasmania between 2001/02 and 2004/05 (few data were available from south-western Tasmania during 2001/02).

3.3.4.3 Mid-water trawl and purse seine operations: 2009/10

A total of 377 Jack Mackerel (107 mid-water trawl and 270 purse seine caught) were aged during 2009/10 (Table 3.3) and an age length key developed to determine the catch age structure for 2009/10. Mid-water trawl and purse seine catches from eastern Tasmania were dominated by 2–3 year old individuals (Fig. 3.19). In comparison with catches from earlier years these findings indicate a shift towards younger age groups. The age structure of the single catch monitored from south-west Tasmania also showed a high proportion of 2 year old fish, representing an estimated 70% of the distribution.

Table 3.3 Summary of shots sampled in the SPF off Tasmania for Jack Mackerel age data during 2009/10. The number of individuals (n) aged is indicated along with the age range and average.

Sampling month	Location	Gear type	n	Age range (years)	Average age (years)
Jul–09	South-west	Midwater trawl	20	1–3	2.2
Aug–09	East coast	Midwater trawl	47	2–4	2.7
Sep–09	East coast	Midwater trawl	40	2–7	2.5
Oct–09	East coast	Purse seine	20	2–3	2.3
Dec–09	East coast	Purse seine	20	2–6	3.1
Jan–09	East coast	Purse seine	20	2–4	2.5
Feb–10	East coast	Purse seine	80	2–7	2.4
Mar–10	East coast	Purse seine	40	1–6	3.0
May–10	East coast	Purse seine	20	2–4	3.0
Jun–10	East coast	Purse seine	70	2–5	3.3

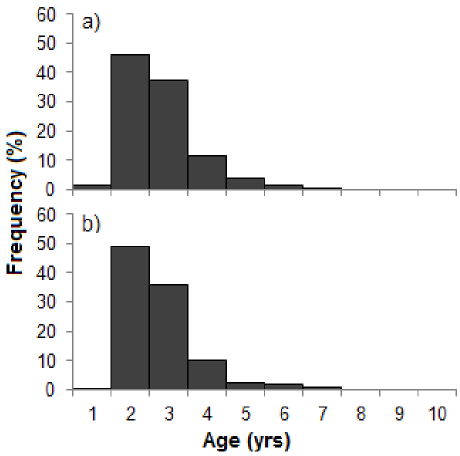

Figure 3.19 Age distribution of Jack Mackerel caught in the SPF off eastern Tasmania by (a) purse seine and (b) mid-water trawling during 2009/10.

3.3.5 Reproduction

An estimate for age at sexual maturity for the south-western Jack Mackerel population is not available due to limited samples.

3.3.5.1 Gonosomatic index (GSI) and gonad stages

Trends in male and female GSI and female macroscopic staging indicate that Jack Mackerel have a discrete spawning season extending over a 3 month period during late spring and early summer (Figs. 3.20, 3.21). The GSIs rose sharply in November with a maximum of 2.6% recorded in January, followed by a sharp decline thereafter.

Fish with hydrated, running ripe and spent gonads (Stages IV–VI) were first evident in November and became more abundant during December-January.

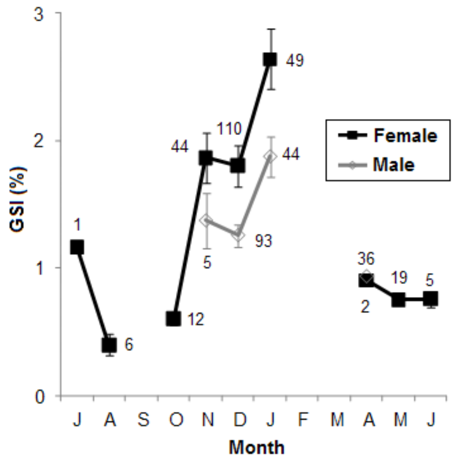

Figure 3.20 Monthly mean GSIs of Jack Mackerel by sex off eastern Tasmania. Numbers associated with data points represent sample size and error bars are standard error.

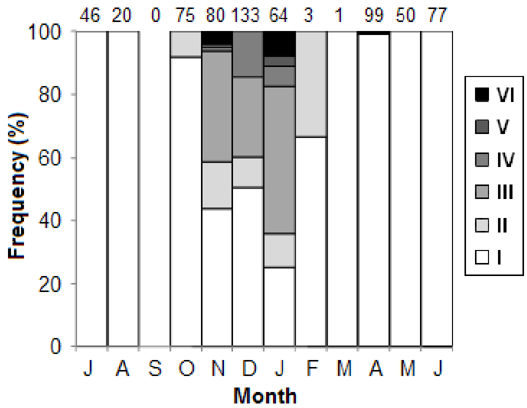

Figure 3.21 Monthly distribution of female Jack Mackerel macroscopic gonad stages off eastern Tasmania. Numbers represent sample sizes.

3.3.5.2 Size at maturity

Size at sexual maturity showed slight differences between males and females with 50% maturity occurring at a smaller size in females (Table 3.4, Fig. 3.22). The size at 50% sexual maturity was 268 mm FL for females and 291 mm FL for males. All fish larger than 360 mm FL were mature.

Table 3.4 Size at sexual maturity logistic parameters and 50% maturity (L_{50}) values of Jack Mackerel, by sex, off eastern Tasmania.

			Size at maturity		
Region	**Sex**	**N**	**a**	**b**	**L_{50} (mm)**
Eastern Tasmania	female	333	–8.40	0.031	268
	male	309	–6.40	0.022	291

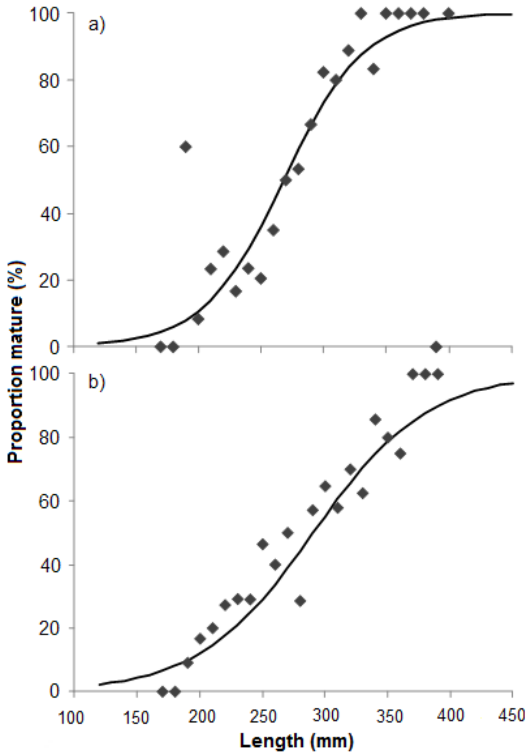

Figure 3.22 Proportion of mature female (a) and male (b) Jack Mackerel by length class with logistic ogives fitted.

3.3.6 Biomass Estimates and MSE

A DEPM analysis by Neira (2011) estimated the spawning biomass of Jack Mackerel to be ~114,000–169,000 t between Sugarloaf Point and Cape Howe (East) during October 2002. This estimate is considered to be imprecise due to the lack of locally collected species-specific reproductive parameters and the lack of a validated temperature-dependant incubation model to age eggs. The estimate is also considered to be conservative (negatively biased) as the surveys did not cover the entire spawning area.

The MSE model was used to test a range of management/harvest scenarios under the harvest strategy for all stocks in the SPF (Giannini *et al*. 2010). Only one stock was modelled for Jack Mackerel. As there were no DEPM survey estimates for spawning biomass to differentiate the stocks (at the time of assessment), model conditions were the same for both East and West stocks. The Tier 1 scenarios investigated using the MSE all reached equilibrium at around B_{40} by the end of the 30 year simulation period. The Tier 2 and Tier 3 results suggest that these harvest levels are conservative and sustainable, however, these should be treated with caution as harvest quantities are “absolute” values and were done without a DEPM estimate of spawning biomass to provide a benchmark. As a DEPM spawning biomass estimate is now available for Jack Mackerel, incorporation of this information into the MSE warrants consideration.

There have been limited stock assessments of Yellowtail Scad in Australia. Stewart and Ferrell (2001) found that the majority of Yellowtail Scad landed in NSW were 2 and 3 year olds. A recent provisional DEPM spawning biomass estimate (Neira 2009) suggests a biomass of ~2,900–5,900 t depending on the model used to estimate daily egg production. This estimate was based on samples collected during a survey in October 2002 directed at Blue Mackerel. There is significant uncertainty around both egg identification and some adult parameters so this result must be viewed with caution.

3.4 Summary and Conclusions

The large fluctuations in production levels throughout the history of the fishery for Jack Mackerel may be the result of a combination of changes in fish availability/abundance and market/economic factors. The potential effects of fishing on abundance and population structure are poorly understood. Several authors have documented the large inter-annual variability in oceanographic conditions in the southern part of the east Australia current (e.g. Harris *et al.* 1992; Young *et al.* 1993; McLeod *et al.* 2012). It has been suggested that the apparent change from Jack Mackerel to Redbait as the dominant small pelagic fish in this region during the 1990s may have been the result of changes in the planktonic assemblage resulting from variations in these oceanographic conditions (Harris *et al.* 1992; Young *et al.* 1993; McLeod *et al.* 2012).

The mid-water trawling for small pelagic fish in the early 2000s was replaced by the resumption of small scale purse seine operations in the late 2000s. Reduced mid-water trawl effort coupled with limited purse seine activity has meant that production levels have been low in recent years. There is no evidence to suggest that these reductions in catches reflect a reduction in stock abundance.

Between 1984/85 and 1990/91, purse seine catches were dominated by 4 and 5 year olds, with over 90% of the catch being over 3 years of age. By contrast, between 1991/92 and 2004/05, the catches were increasingly dominated by 3 and 4 year olds and in 2009/10, 2 and 3 year olds were the dominant age classes in both the purse seine and mid-water trawl catches. While fishery impacts are plausible in the early stages of the fishery due to high catch levels, more recent catches have been relatively small (reflecting limited effort) and may therefore reflect recruitment variability and/or targeting practices.

Ecosystem modelling of south east Australian waters indicates that the spawning biomass of Jack Mackerel is likely to be in the vicinity of 130,000–170,000 t (Fulton 2013), which is consistent with the estimates provided by Neira (2011). There is no evidence to suggest that recent low catches of Jack Mackerel in either region are not sustainable. The need for DEPM assessments of Jack Mackerel in both zones warrants consideration.

4 REDBAIT (*EMMELICHTHYS NITIDUS*)

4.1 Introduction

4.1.1 Background to Fishery

Redbait represented a key by-product species taken by the purse seine fishery for Jack Mackerel (*Trachurus declivis*) that developed off Tasmania in the mid–1980s, with catches peaking at over 40,000 t in 1986/87. Redbait rarely exceeded 5% by weight of the landed catch in any year but the high volume of production meant that annual landings in the order of 1,500 t were taken between the mid–1980s and early 1990s.

In 2001/02, a 6–month fishing trial involving a mid-water, pair-trawl operation was established to target subsurface schools of Jack Mackerel to reduce dependence on the availability of surface schooling fish. A total catch of over 5,000 t was taken between December 2001 and April 2002, nearly 90% of which was Redbait. On the strength of this trial, a multipurpose 50 m mid-water trawler was brought to Tasmania to target small pelagic species, in particular Redbait, with fishing operations commencing in late 2002. Catches of Redbait from mid-water trawling were nearly 7,000 t in 2002/03 and comprised up to 94% of the total catch.

More recent fishing for small pelagic fish by purse seine in Tasmanian State waters yielded 300 t of Redbait in 2007/08, 521 t in 2008/09 and 122 t in 2009/10 (Hartmann and Lyle 2011). There were no Redbait catches in Tasmania in 2010/11 or 2011/12. Redbait are primarily frozen whole for use as feed for farmed southern bluefin tuna (*Thunnus maccoyii*), and are also used along with Jack Mackerel in the production of fish meal for use in the aquaculture industry.

4.1.2 Taxonomy

Redbait (*Emmelichthys nitidus* Richardson 1845) belong to the family Emmelichthyidae, of which there are 3 genera and 15 species (Nelson 2006). Emmelichthyids are widespread, found throughout tropical and temperate waters in both hemispheres. They are generally found in schools over continental shelf breaks, seamounts and submarine ridges. They inhabit depths from the surface to >800 m, though they are mostly recorded from mid-water trawls in 100–400 m water (Heemstra and Randall 1977; Markina and Boldryev 1980; Last *et al.* 1983; Nor *et al.* 1985; May and Maxwell 1986; Smith and Heemstra 1986; Mel'nikov and Ivanin 1995; Parin *et al.* 1997). Redbait are one of two species of emmelichthyid found off southern Australia, the other being the rubyfish (*Plagiogeneion rubiginosum*) (Last *et al.* 1983; May and Maxwell 1986; Gomon *et al.* 2008).

4.1.3 Distribution

Redbait are widely distributed throughout the southern hemisphere, with the species reported from Tristan da Cunha in the southern Atlantic, the south-western coast of South Africa, St Paul and Amsterdam Islands, mid-oceanic ridges and seamounts through the Indian Ocean, Australia, New Zealand, submarine ridges in the south-eastern Pacific, and the southern coast of Chile (Heemstra and Randall 1977; Markina and Boldryev 1980; Meléndez and Céspedes 1986; Oyarzún and Arriaza 1993; Parin *et al.* 1997; Gomon *et al.* 2008). Within Australian waters, their range extends from mid NSW to south-west Western Australia, including Tasmania (Gomon *et al.* 2008).

4.1.4 Stock Structure

There have been no targeted stock structure studies on Redbait in Australia. However, on the weight of evidence, Bulman *et al*. (2008) concluded that Redbait from eastern Australia and eastern Tasmania were likely to be a single stock. The situation for western Tasmania and the GAB is less clear but the observation that fish off eastern and south-western Tasmania exhibit some biological differences (Neira *et al.* 2008) provides some evidence for separation into eastern and western stocks around Tasmania.

4.1.5 Movement

No studies have investigated Redbait movement.

4.1.6 Food and Feeding

A study of the diet of Redbait in South African coastal waters indicated that the smaller size classes (136–280 mm) feed exclusively on small planktonic crustaceans, with euphausiids (*Nyctiphanes* and *Euphausia* spp.), hyperiid amphipods (primarily *Themisto gaudichaudi*), mysids and large copepods accounting for the entire diet (Meyer and Smale 1991). Larger individuals (281–493 mm) also feed for the most part on small planktonic crustaceans, but nekton such as cephalopods, carid shrimp, and small fishes including myctophids, also constituted a component of the diet (Meyer and Smale 1991). Redbait of unspecified size captured on the shelf off eastern Victoria had a varied diet, dominated by pelagic crustaceans and other pelagic invertebrates including gelatinous zooplankton (Bulman *et al.* 2000; Bulman *et al.* 2001). Similarly, Redbait captured off eastern Tasmania in 2003 and 2004 had a diet dominated by pelagic crustaceans, with krill (*Nyctiphanes australis*) and copepods comprising 65.7% and 33.2% of relative importance indices, respectively (McLeod, 2005).

The diet of Redbait shows parallels with that of Jack Mackerel (*T. declivis*) from Tasmania, with krill *N. australis* representing the dominant prey item eaten on the continental shelf (Young *et al.* 1993; McLeod 2005). Since Redbait, Jack Mackerel and Blue Mackerel form mixed species schools in Tasmanian waters (Williams and Pullen 1993) it is likely that these species feed on similar prey species.

4.1.7 Age, Growth and Size

The maximum reported size of Redbait from Tasmania is 317 and 304 mm FL for females and males, respectively (Neira *et al.* 2008), somewhat smaller than that recorded elsewhere throughout their distributional range. Redbait have been confirmed to grow to 335 mm FL off eastern Victoria (Furlani *et al.* 2000), 344 mm standard length (SL) off the coast of Chile (Meléndez and Céspedes 1986) and individuals of 493 mm total length (TL) and possibly larger have been caught in South African waters (Heemstra and Randall 1977; Meyer and Smale 1991). Redbait are observed to school by size, and also stratify by depth, with larger (>200 mm) Redbait often found deeper and closer to the seafloor than schools of smaller fish (Markina and Boldryev 1980).

Estimates of growth for Redbait, derived from either interpretation of scales (Roschin 1985), whole otoliths (Williams *et al.* 1987) or sectioned otoliths (Neira *et al.* 2008), suggest that it is rapid in the first years of life. Redbait from Tasmanian waters reached a mean FL in excess of 200 mm in the first three years, with growth slowing thereafter (Neira *et al.* 2008). The maximum estimated age for Redbait based on sectioned otoilths is 21 and 18 years for females and males, respectively (Neira *et al.* 2008). The much larger Redbait reported from Africa (e.g. Meyer and Smale 1991) suggest that the maximum age in this species may be higher than indicated from Tasmanian samples, and that growth is highly variable regionally. Unvalidated ageing of rubyfish in New Zealand, using otolith sections, has produced age estimates in excess of 80 years for fish over 400 mm (Paul *et al.* 2000). However, as ageing methods have not been fully validated for any emmelichthyid species, current estimates of growth or maximum age need to be considered with caution.

4.1.8 Reproduction

Redbait is an asynchronous batch spawner with indeterminate fecundity. Annual trends in GSI and macroscopic gonad stages indicated that Redbait from eastern Tasmania spawn between September and November, with peak activity during

September and October (Ewing and Lyle 2009). There are marked regional differences in size and age at sexual maturity, with males and females from south-western Tasmania (261 and 244 mm, respectively) maturing at some 100 mm larger and two years older compared to Redbait from eastern Tasmania (157 and 147 mm, respectively). Spawning occurs along a narrow 2.5 nm corridor either side of the shelf break when mid-water temperatures are 12.0–15.2°C (Neira *et al.* 2008).

4.1.9 Early Life History and Recruitment

Redbait eggs are positively buoyant and hatch approximately 2–4 days after fertilisation depending on temperature (Neira *et al.* 2008). Newly hatched yolk sac larvae range from 1.9 to 3.3 mm TL. Although spawning areas (eggs and larvae) have been described by Neira *et al.* (2008), little is known about the early life history of Redbait post-hatching.

4.1.10 Stock Assessment

Spawning habitat of Redbait was described from egg, larval and environmental data collected over shelf waters between north-eastern Bass Strait and lower south-western Tasmania in 2005 and 2006 (Neira *et al.* 2008). The DEPM was subsequently applied to estimate the spawning biomass of Redbait within this region (Neira *et al.* 2008; Neira and Lyle 2011).

4.1.11 Management

A DEPM assessment has been conducted for the East, the fishery is managed at the Tier 2 level and as such TACs have been set based on the rules outlined by the SPF harvest strategy. The fishery is considered to not be overfished (Woodhams *et al.* 2012).

4.2 Methods

4.2.1 Fishery Statistics

Commercial operators participating in the Zone A Jack Mackerel purse seine fishery were required to complete logbooks recording catch and effort from the inception of the fishery in 1984. The initial logbook comprised a shot by shot record of fishing operations, including species breakdown. This was replaced for the 1990/91 fishing year with a trip catch return, in which catch composition was not routinely reported, just total landings of small pelagic fish. Trawl operations since 2001/02 have been reported in the Commonwealth South East Fishery trawl logbook, providing a shot by shot record of catch and effort, including catch composition. When purse seine operations targeting small pelagic fish resumed in Tasmanian State waters, shot by shot catch and effort data were recorded in the Tasmanian general fishery logbook.

4.2.2 Biological Information

Fishery dependent length frequency and biological data for Redbait were collected between 1984 and 1993 as part of a monitoring program of the Jack Mackerel purse seine fishery. Some biological information was also collected from samples of Redbait collected from demersal research trawling conducted by CSIRO and the relevant Tasmanian fisheries agency between 1985 and 1990. Between 1994 and 2001 the level of catch sampling of the purse seine fishery was limited and targeted mainly at Jack Mackerel.

Collection of biological data during the 2001/02 pair-trawl fishing trials was undertaken by AFMA observers on a small proportion of trips, so data were limited and may not be representative of the catch. Following the commencement of mid-water trawl operations in 2002, TAFI commenced an intensive biological monitoring program that continued to 2006. AFMA also provided observer coverage of mid-water trawl operations, with additional length frequency data collected from 2002 to 2008.

Purse seine operations for small pelagic fish resumed in Tasmanian State waters during 2008/09, with Redbait and Jack Mackerel the main species targeted. Catch sampling of mid-water trawl and purse seine operations adjacent to Tasmania was implemented in 2009/10 as part of the SPF monitoring program under the SPF Harvest Strategy framework (AFMA 2008).

Biological data were collected from individual specimens and included FL (to the nearest millimetre), total weight (to the nearest gram), sex, gonad developmental stage (following the macroscopic staging criteria described in Marshall *et al.* 1993) and gonad weight (to the nearest 0.1g). Otoliths were also extracted and used for age estimation and growth modelling (Williams *et al.* 1987).

Commercial logbook information, length frequency and biological data collected over the period 1984–2010 were available for the present review. Age growth and reproductive data for Redbait were available from previous studies by Welsford and Lyle (2003) and Neira *et al.* (2008). In addition, specimens from 2009/10 mid-water trawl and purse seine fishing operations have been analysed to provide size and age composition estimates of the catch. No biological information was collected for 2010/11 or 2011/12.

4.2.3 Biomass Estimates and MSE

A detailed study on the early life history, reproduction and stock assessment of Redbait was conducted between 2004 and 2006, with spawning biomass estimated using the DEPM from egg and adult reproductive data collected off eastern Tasmania during October 2005 and 2006 (Neira *et al.* 2008).

4.3 Results

4.3.1 Fishery Statistics East / West

4.3.1.1 Number of vessels

No vessels reported landing Redbait in either the Eastern or Western part of the fishery in 2011/12 (Figs. 4.1 and 4.2).

4.3.1.2 Annual Patterns-catch, effort & catch-per unit effort

Prior to 2001/02 Redbait catches in the East were negligible (<200 t). Catches increased to ~3,800 t in 2001/02 and 2002/03 and peaked at ~7,000 t in 2003/04. Catches have sequentially declined over the past six years to ~400 t in 2009/10 (Fig. 4.3) with nil catch reported in 2011/12. Annual estimates of effort have displayed a similar trend, rapidly increasing from <40 vessel days pre–2001/02 to >100 vessel days in 2003/04 and subsiding back to <40 vessel days in recent years (Fig. 4.4). Redbait catch rates in the East peaked at ~70 t.vessel day^{-1} in 2001/02, remained above 40 t from 2002/03 to 2005/06 then declined to ~20 t.vessel day^{-1} in 2009/10 (Fig. 4.4).

Redbait catches in the West were lower than the East (Fig. 4.5). Like the East the trend in catches in the West also displayed a clear peak, but it occurred a few years later, with catches exceeding 3,000 t in 2005/06. Catches have not exceeded 1,000 t since 2008/09 (Fig. 4.5) and nil catch was reported in 2011/12. The trend in catch has reflected the trend in annual fishing effort (Fig. 4.5). Fishing effort peaked at ~90 vessel days in 2005/06 and over the past two years has been <30 vessel days. Redbait catch rates in the West have sequentially declined from ~100 $t.vessel\ day^{-1}$ in 2001/02 to ~30 $t.vessel\ day^{-1}$ in 2009/10 (Fig. 4.6).

4.3.1.3 Inter-annual Patterns-catch and effort

In the years 1997/98 to 2002/03, most of the Redbait catch in the East was taken during late summer and autumn (Fig. 4.7). From 2003/04 to 2008/09, Redbait were also caught during winter and spring. Annual peaks in Redbait catches during this time generally occurred during late autumn and winter. The seasonality of catches in the West were more discrete and generally confined to autumn and winter (Fig. 4.8). Catches were only prominent during summer in 2008/09. Trends in catch generally followed trends in effort in both zones.

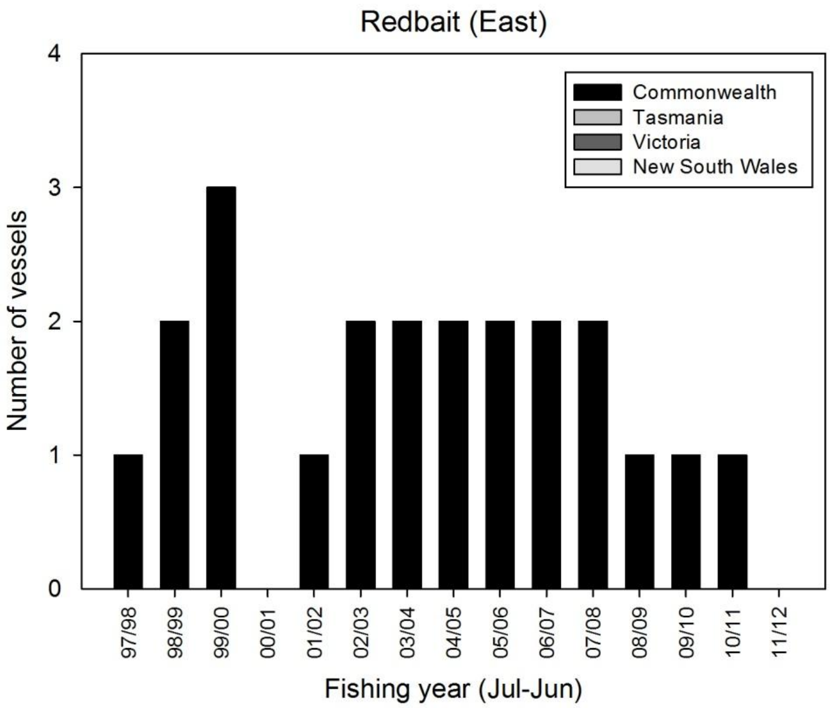

Figure 4.1 Number of vessels which landed Redbait in the East.

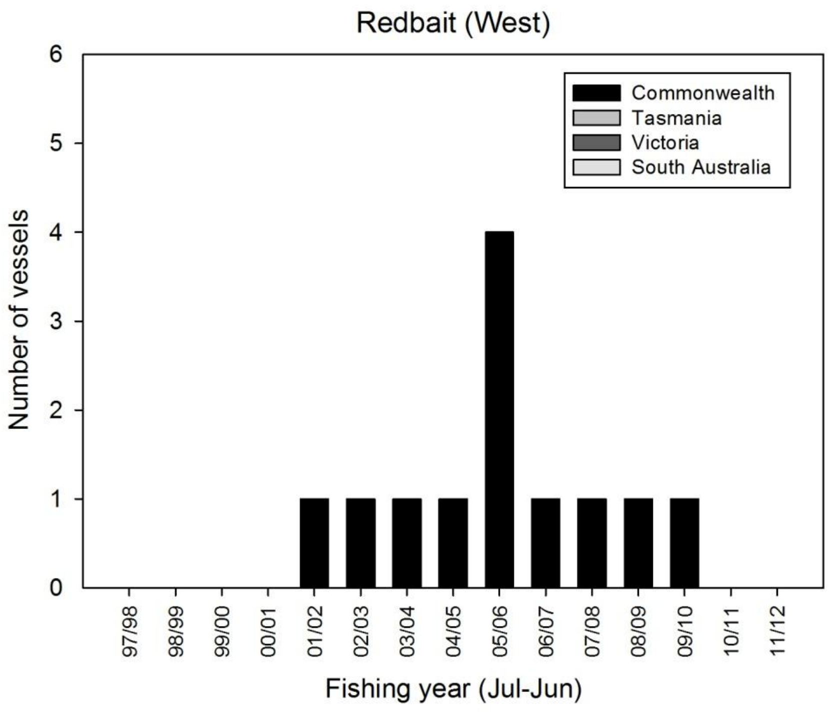

Figure 4.2 Number of vessels which landed Redbait in the West.

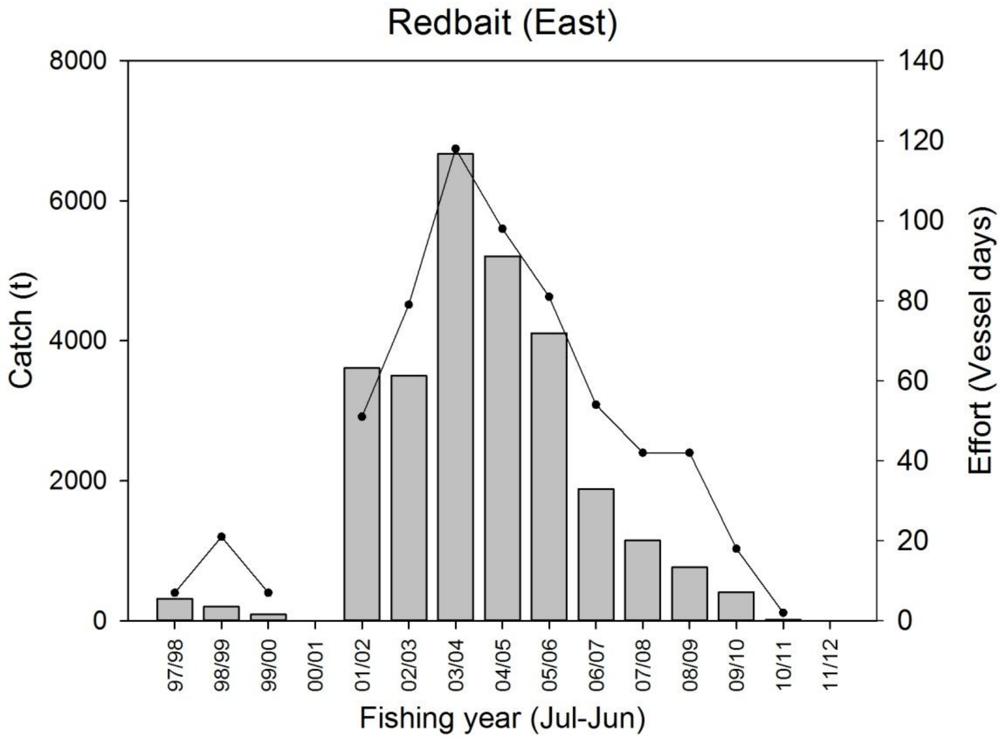

Figure 4.3 Total landed catch (t, bars) and effort (vessel days, line) for Redbait in the East during financial years over the period 1997/98–2011/12.

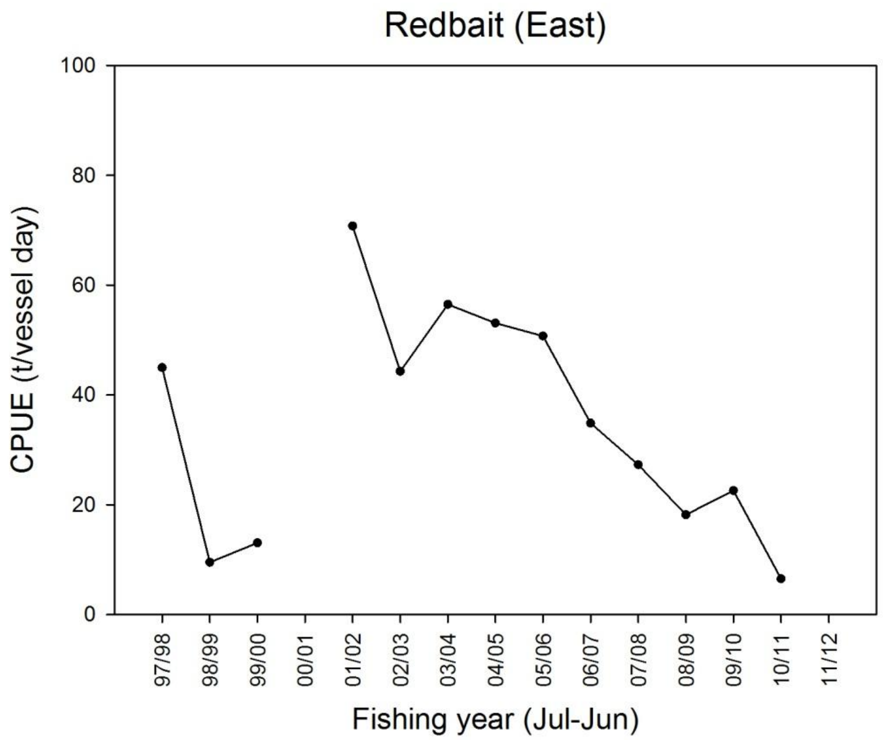

Figure 4.4 CPUE (t per vessel day) for Redbait in the East during financial years over the period 1997/98–2011/12.

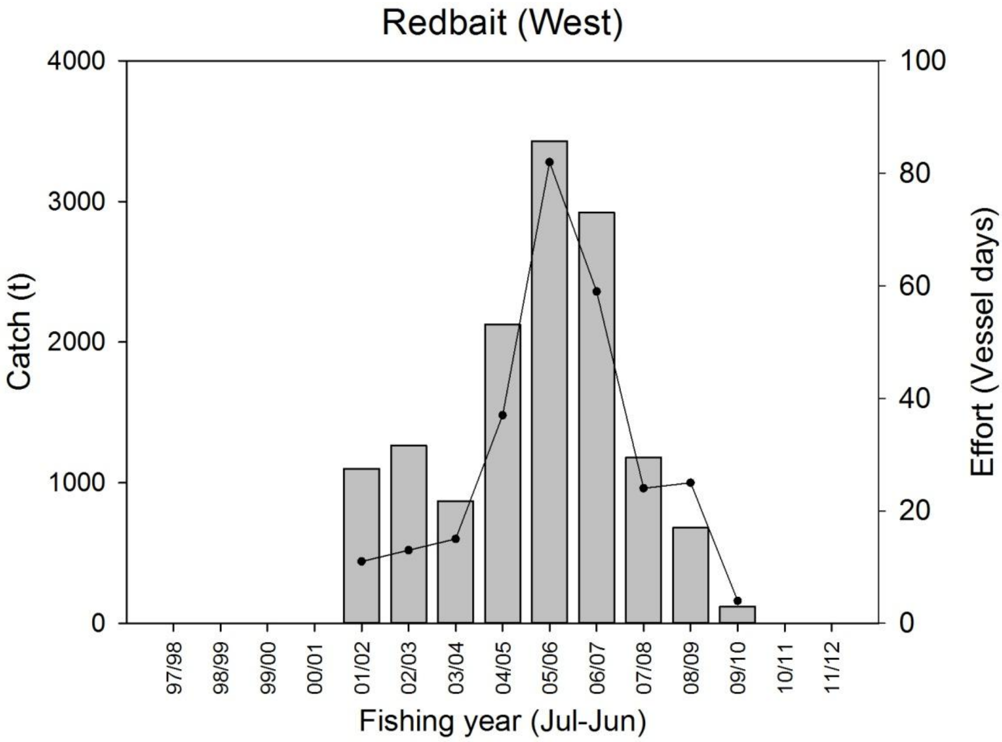

Figure 4.5 Total landed catch (t, bars) and effort (vessel days, line) for Redbait in the West during financial years over the period 1997/98–2011/12.

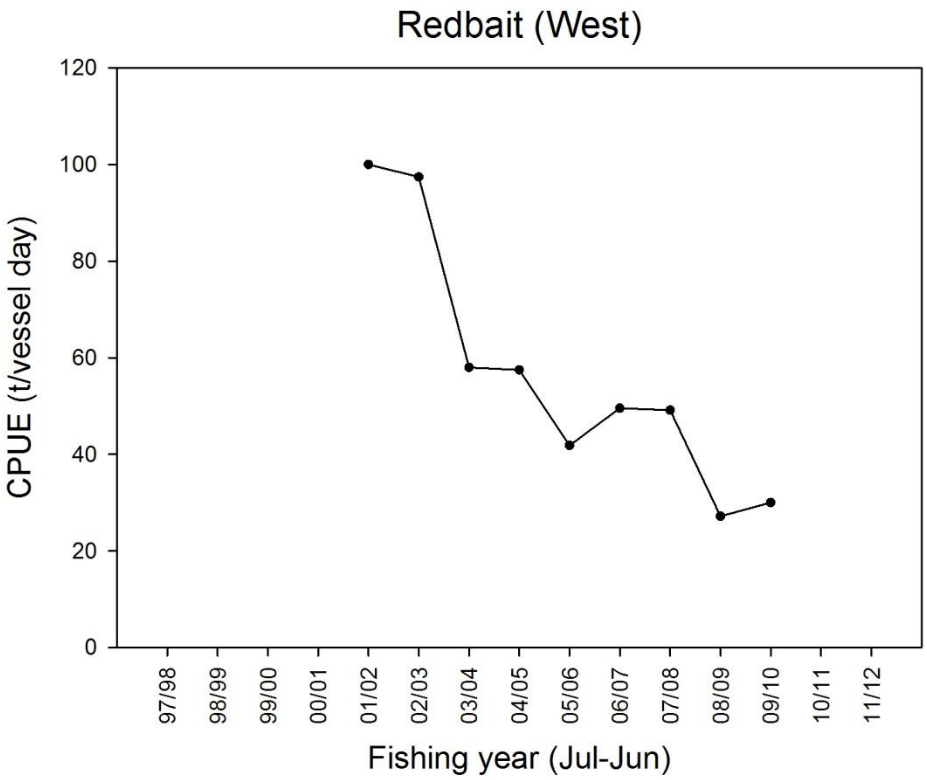

Figure 4.6 CPUE (t per vessel day) for Redbait in the West during financial years over the period 1997/98–2011/12.

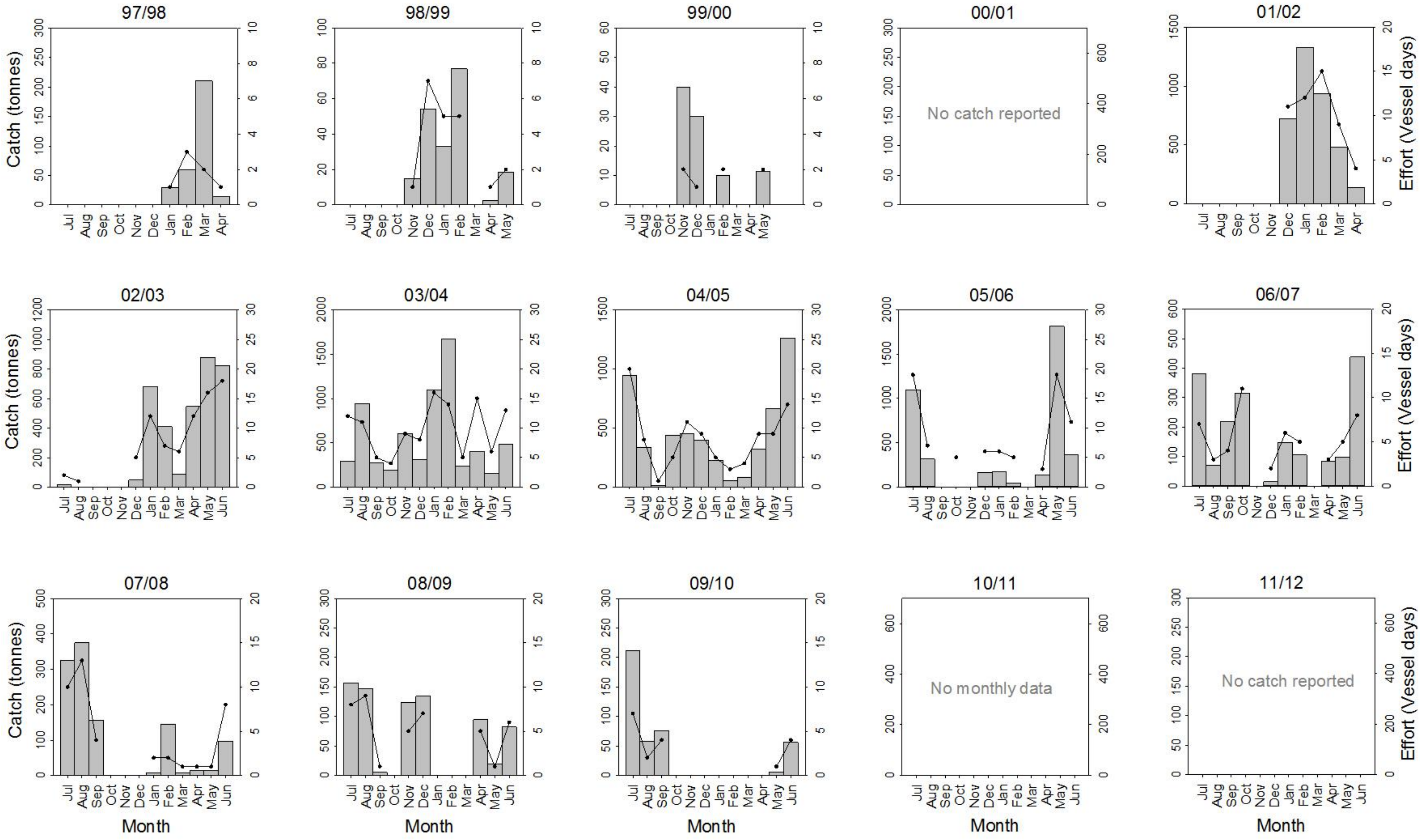

Figure 4.7 Inter-annual patterns of catch (bars) and effort (line) for Redbait in the East for the period from 1997/98 to 2011/12.

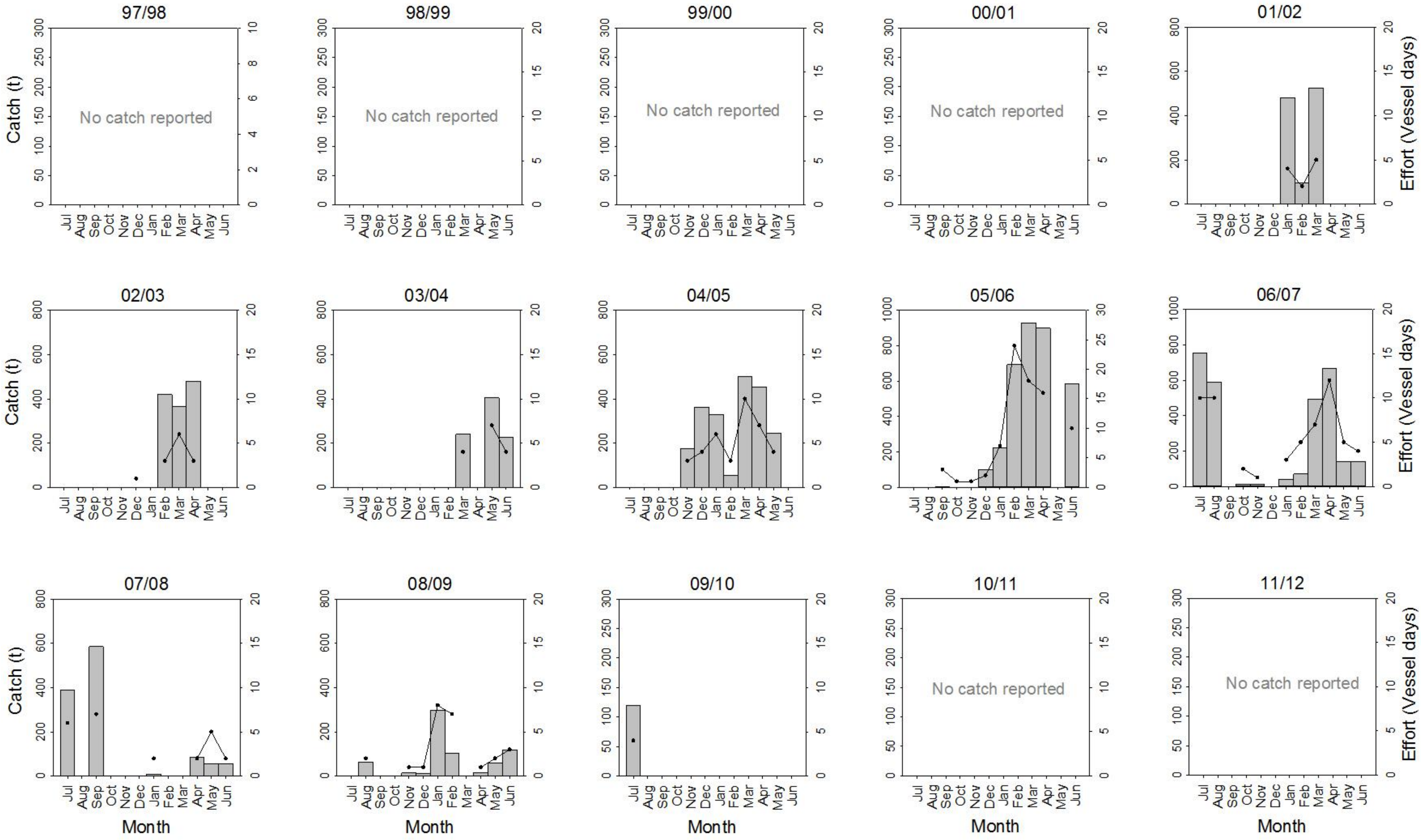

Figure 4.8 Inter-annual patterns of catch (bars) and effort (line) for Redbait in the West for the period from 1997/98 to 2011/12.

4.3.2 Biological Information

4.3.2.1 Size Structure

The purse seine fishery: 1984/85–2009/10

Redbait caught in the Jack Mackerel purse seine fishery between 1984/85 and 1994/95 off eastern Tasmania were mostly 140–290 mm FL, with individuals up to 320 mm recorded (Figs. 4.9, 4.10). Catches between 1984/85 and 1987/88 were dominated by fish of 200–300 mm, with only a few small fish (100–140 mm) caught in 1985/86. A strong mode (cohort) of smaller fish (120–170 mm) was present in 1988/89 and this cohort appeared to account for the majority of the catch in the following year. Between 1989/90 and 2009/10, smaller fish (<200 mm) tended to dominate the composition of the catch (Fig. 4.9). No data for 2010/11 or 2011/12 were available.

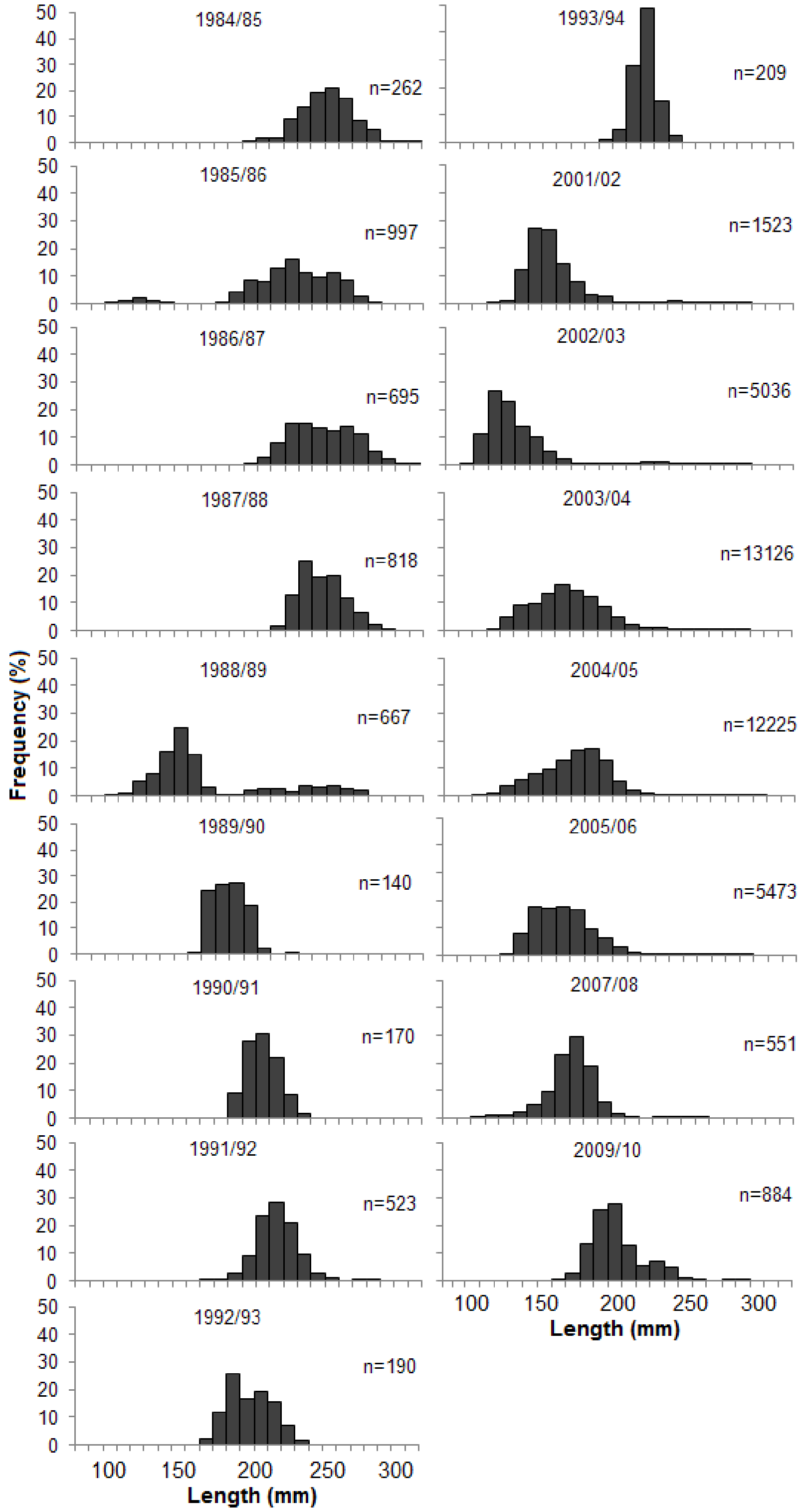

Figure 4.9 Length frequency distributions of Redbait caught in the SPF by purse seine operations off eastern Tasmania from 1984/85 to 2009/10.

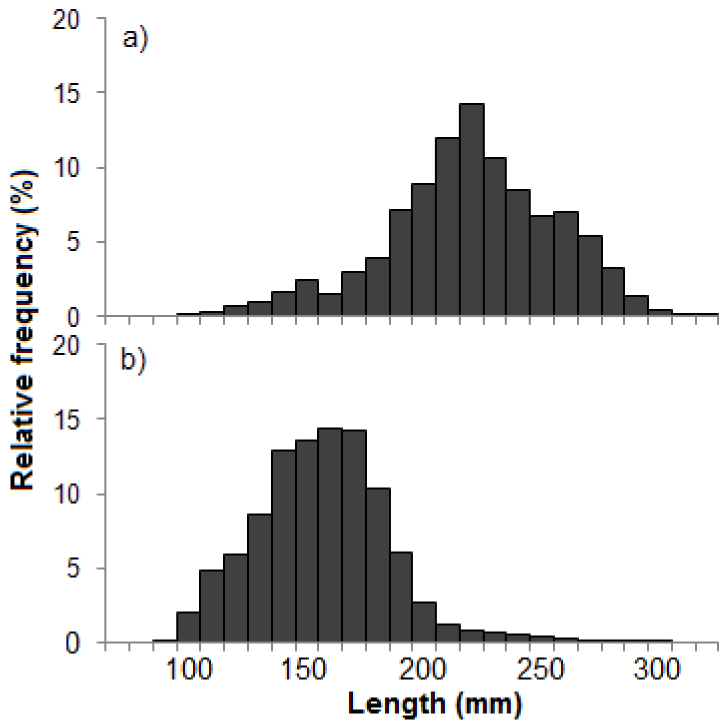

Figure 4.10 Year-weighted length frequency distributions of Redbait caught in the SPF off eastern Tasmania from (a) purse seine operations (1984/85–1994/95) and (b) mid-water trawl operations (2001/02–2008/09).

Mid-water trawl fishery: 2001/02–2008/09

Redbait caught by mid-water trawl operations between 2001/02 and 2008/09 off eastern Tasmania were considerably smaller than those caught by the earlier purse seine operations, with specimens mostly between 100 and 210 mm (Fig. 4.11, 4.12). Annual size distributions show east coast catches were consistently comprised of high numbers of small fish with modes varying between 120 mm (2002/03) and 180 mm (2004/05) (Fig. 4.9). Only a small proportion of the catch was made up of fish larger than 200 mm. By contrast Redbait caught by mid-water trawl operations off south-western Tasmania were mostly between 130–280 mm with a modal length of 200 mm (Figs. 4.11, 4.12). While the south-west coast frequency distribution in 2001/02 was comprised mainly of small fish and mirrored that of the east coast catch in that year, substantially larger individuals dominated south-west coast catches in subsequent years. Overall the size structure of Redbait catches from south-western Tasmania was bi-modal with peaks at around 140 and 200 mm (Fig. 4.12).

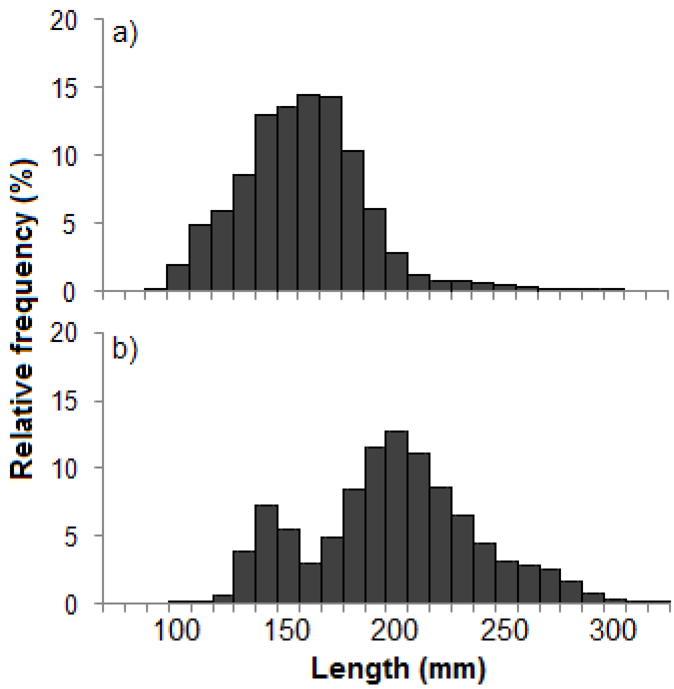

Figure 4.11 Year-weighted length frequency distributions of Redbait caught in the SPF off (a) eastern and (b) south-western Tasmania from mid-water trawl operations between 2001/02 and 2006/07.

Mid-water trawl and purse seine operations: 2009/10

A total of 887 Redbait were sampled from 12 landings based on purse seine and mid-water trawl operations off eastern Tasmania between August 2009 and June 2010 (Table 4.9).

Mid-water trawl catches from eastern Tasmania were dominated by 190–240 mm fish (Fig. 4.12). By contrast, 180–200 mm FL fish comprised the bulk of the purse seine catch, few individuals larger than 210 mm were present (Fig. 4.12). In many respects the purse seine catch size structure was more typical of mid-water trawl catches from eastern Tasmania during the early 2000s than that for the recent mid-water trawl landings.

A single catch (taken in early 2009) from south-western Tasmania was also available and comprised of 210–310 mm FL fish (mode 240 mm), which was consistent with the size of fish taken in previous years from that zone (Table 4.1).

Table 4.1 Summary of shots sampled in the SPF off Tasmania for Redbait length-frequency data between Feb–09 and Jun–10. The number of individuals (n) for which length-frequency data was collected along with the size range and modal length are indicated.

Sampling month	No. of shots	Location	Gear type	n	Size range (mm)	Mode (mm)
Feb–09	1	South-west	Midwater trawl	77	210–310	240
Aug–09	2	East coast	Midwater trawl	129	180–240	210
Sep–09	3	East coast	Midwater trawl	200	170–270	210
Jan–10	1	East coast	Purse seine	20	190–230	200
Feb–10	2	East coast	Purse seine	157	170–230	200
May–10	1	East coast	Purse seine	75	180–220	200
Jun–10	1	East coast	Midwater trawl	64	210–300	240
Jun–10	2	East coast	Purse seine	242	170–220	200

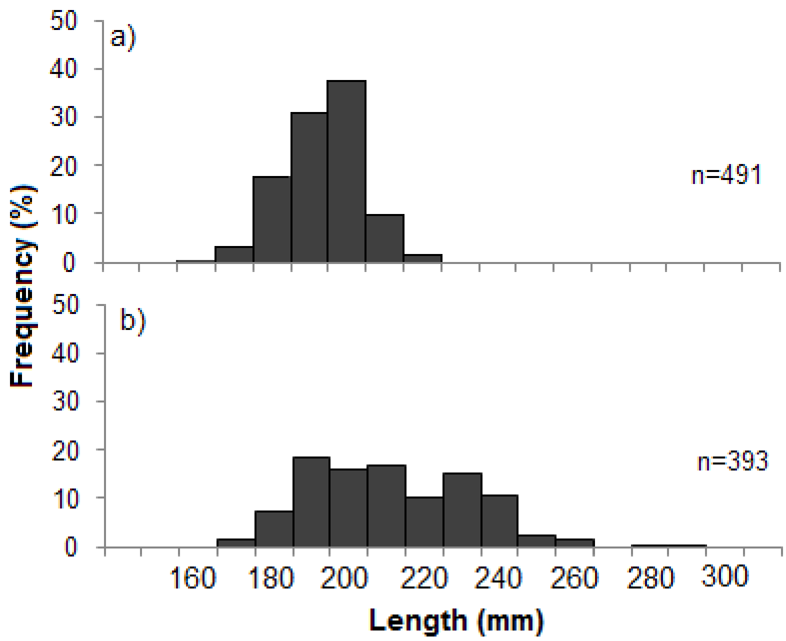

Figure 4.12 Length frequency distribution of Redbait caught in the SPF eastern Tasmania by purse seine (a) and mid-water trawling (b) operations during 2009/10. n is sample size.

4.3.3 Age and growth

Growth of male and female Redbait was described using the von Bertalanffy growth function (VBGF) from eastern and south-western Tasmania (Table 4.2, Fig. 4.13). Growth is rapid within the first years of life with individuals reaching a mean of 200 mm FL in the first three years, with growth slowing thereafter. Maximum assigned ages for females and males reordered were 21 and 18 years, respectively.

Table 4.2 Summary of VBGF parameters by sex and by region. EC and SW refer to eastern and south-western Tasmania and * refers to eastern Tasmanian samples with unsexed juveniles excluded (based on Neira *et al*, 2008).

		VB parameters		
	n	L_∞	K	t_0
EC ♂	326	279.3	0.27	–1.45
EC ♂*	209	282.4	0.23	–2.27
EC ♀	503	297.2	0.22	–1.76
EC ♀*	386	346.1	0.11	–4.56
SW ♂	173	306.6	0.13	–5.49
SW ♀	294	304.8	0.16	–4.46
Pooled	1265	284.1	0.27	–1.54

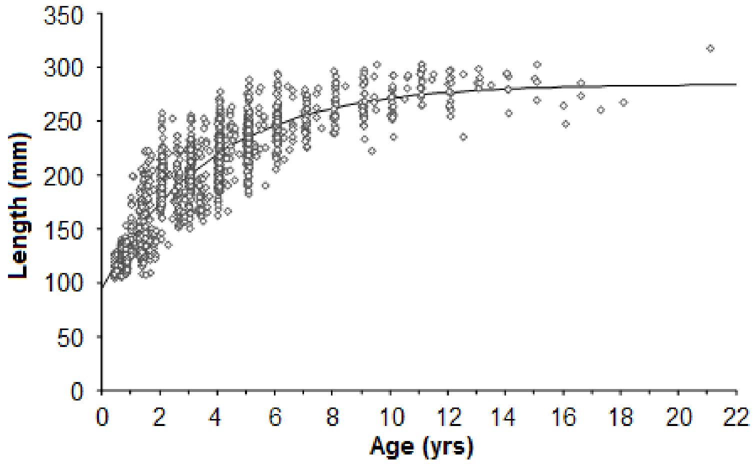

Figure 4.13 Length at age data for Redbait with regions pooled. The grey line represents the VB growth function.

4.3.3.1 Age Structure

4.3.3.1.1 Mid-water trawl fishery: 2001/02–2005/06

The age structure of Redbait caught in the SPF was estimated using age length keys based on age data pooled between 2001/02 to 2005/06 (Fig. 4.14). The eastern Tasmanian catches were comprised mostly of fish aged between 1 and 5 years old. These catches were generally dominated by 2 year olds, except during 2002/03 when 1 year olds accounted for 64% of the catch. The proportion of fish aged 2 and under varied between 40% (2004/05) and 94% (2002/03), with few fish (<4%) caught aged above 5 years old. The age structure of the south-west Tasmanian catches showed a higher proportion of older fish, with catches comprised of fish between 2 and 8 years old. A strong cohort of 2 year old fish dominated catches in the 2003/04 season; this cohort subsequently dominated catches as 3 year olds in 2004/05 and 4 year olds in 2005/06.

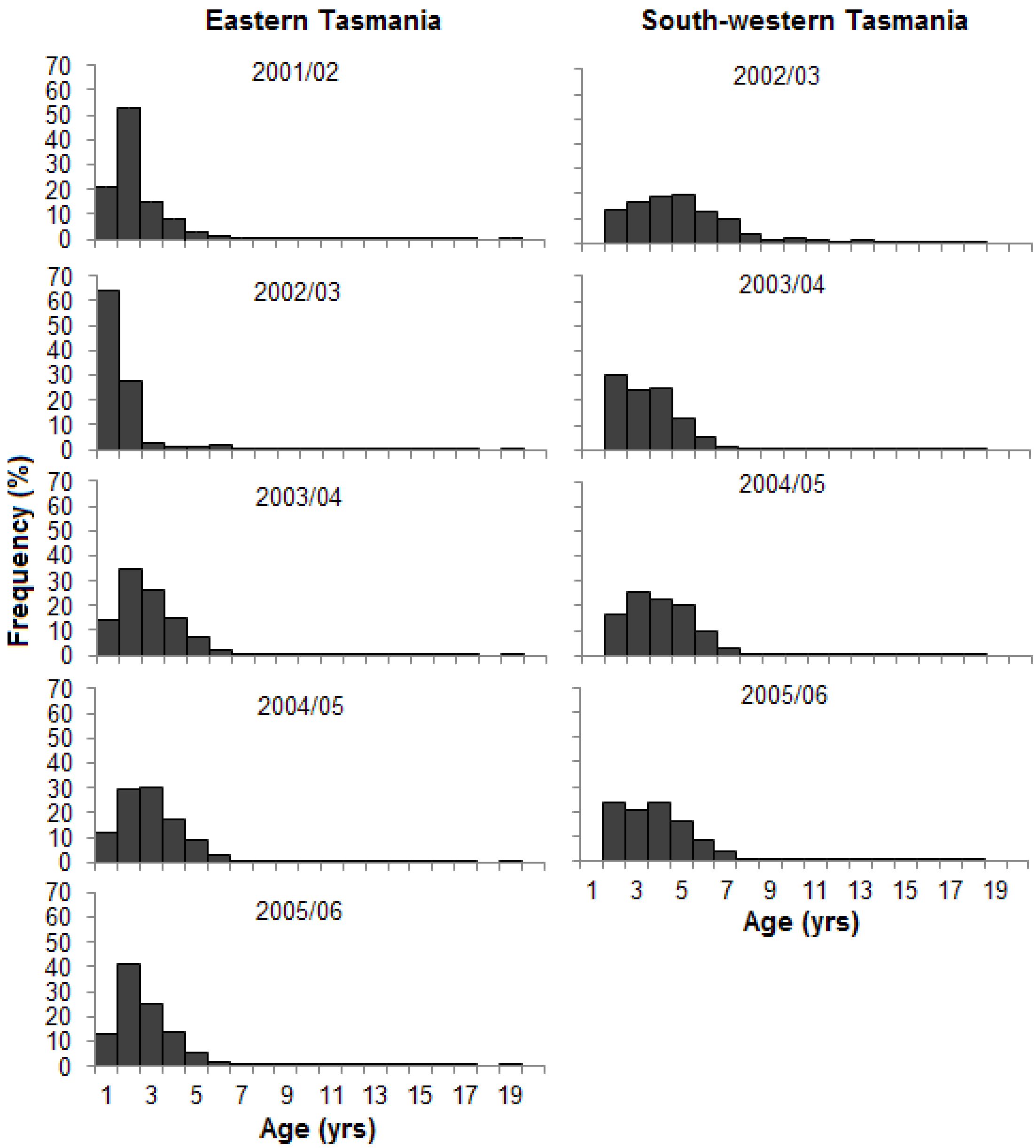

Figure 4.14 Age structure of Redbait catch samples from eastern and south-western Tasmania between 2001/02 and 2005/06. No data were available off south-western Tasmania during 2001/02.

4.3.3.1.2 Mid-water trawl and purse seine operations: 2009/10

A total of 280 Redbait (160 mid-water trawl and 120 purse seine caught) were aged in 2009/10 (Table 4.3) and an age length key developed to determine the catch age structure for 2009/10. The age composition of the mid-water catch from eastern Tasmania was similar to that in previous years, with fish mostly between 2–3 years of age (Fig. 4.15). Purse seine catches were also dominated by 2–3 year old fish, with 2 year olds accounting for over half of the catch.

Specimens aged from the single sample from south-western Tasmania in 2009/10 included individuals that were substantially older than those sampled from east coast catches, with 90% of the catch estimated to be over 4 years of age (Table 4.3).

Table 4.3 Summary of shots sampled in the SPF off Tasmania for Redbait age data during 2009/10. The number of individuals (n) aged is indicated along with the age range and average.

Sampling month	Location	Gear type	n	Age range (years)	Average age (years)
Feb–09	South-west	Midwater trawl	20	2–13	6.2
August–09	East coast	Midwater trawl	40	2–7	2.7
Sep–09	East coast	Midwater trawl	70	1–9	3.3
Jan–10	East coast	Purse seine	20	1–5	2.5
Feb–10	East coast	Purse seine	40	1–2	1.3
May–10	East coast	Purse seine	20	1–3	2.5
Jun–10	East coast	Midwater trawl	30	3–7	4.0
Jun–10	East coast	Purse seine	40	2–3	2.4

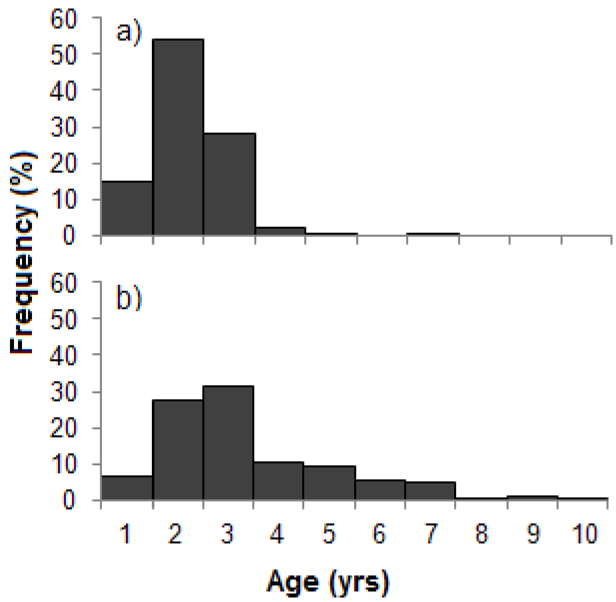

Figure 4.15 Age distribution of Redbait caught in the SPF off eastern Tasmania by (a) purse seine and (b) mid-water trawling during 2009/10.

4.3.3.2 Gonosomatic index

Trends in male and female GSIs indicate that Redbait have a discrete spawning season extending over a 2–3 month period during spring. The GSIs from east coast Redbait rose sharply in August, peaking in September-October before declining to resting levels by January (Fig. 4.16). A similar pattern was evident for south-western

Tasmania, although the GSI peak occurred between October-November, i.e. one month later.

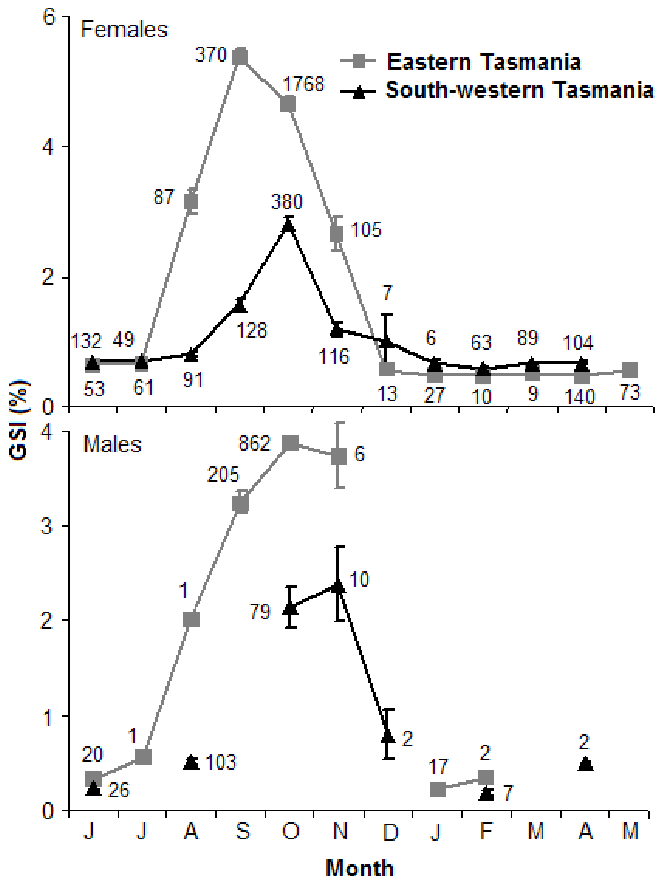

Figure 4.16 Monthly distribution of mean GSI by sex and region. Numbers represent sample size and error bars are standard error. Based on Neira *et al*. (2008).

4.3.3.3 Gonad stages

Macroscopic staging of females confirmed that the seasonal increase in GSIs was attributed to reproductive activity. Fish with maturing gonads (stage III) dominated east coast samples in August and by September over half of the fish examined had hydrated oocytes (stage IV) (Fig. 4.17). Fish with hydrated oocytes were present through to November and spent fish (stage VI) were evident between November and January, implying that limited spawning activity may have extended to December and January. Very few running ripe fish were observed in these samples, possibly an artefact of freezing making such gonads difficult to distinguish from those with hydrated oocytes. Samples collected between January and August were dominated by fish with undeveloped or resting gonads (>90%). A similar pattern of gonad stage development was evident off south-western Tasmania. Spawning season GSIs for south-western Tasmania were consistently lower than those for fish from eastern

Tasmania, presumably in response to the lower proportion of actively spawning fish (≥ stage III) in the samples (Fig. 4.17).

The occurrence of oocyte atresia in histological sections from fish sampled off eastern Tasmania during 2004/05 increased from 11% in fish sampled in late October to 36% of the fish sampled in November. These observations support macroscopic staging by implying that the peak in spawning activity was over by mid-November.

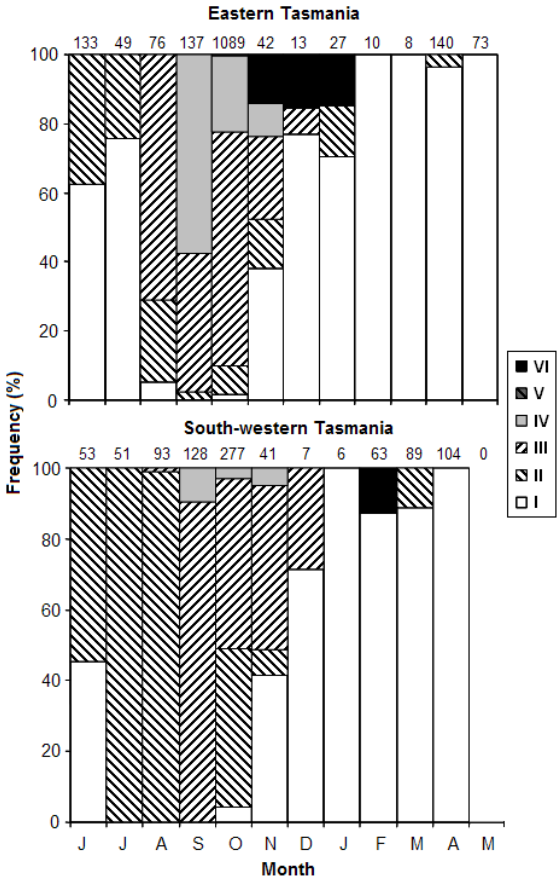

Figure 4.17 Monthly distribution of female macroscopic gonad stages by region. Numbers represent sample sizes. Based on Neira *et al*. (2008).

4.3.3.4 Size and age at maturity

Logistic growth models indicated females attained 50% maturity at larger sizes than males in both eastern and south-western Tasmania, although age at maturity was generally similar between the sexes within a given region (Table 4.4, Figs. 4.18, 4.19). There were, however, marked differences in sizes and ages at maturity between the regions, with both sexes maturing at around 100 mm larger and 2 years older off south-western Tasmania compared with eastern Tasmania. The size (age) at 50% sexual maturity was 147 and 244 mm (4.8 and 2.0 years) for males, and 157 and 261 mm (4.1 and 2.0 years) for females, from eastern and south-western Tasmania, respectively.

Table 4.4 Size and age at sexual maturity logistic parameters and 50% maturity (L50) values by sex and region. Based on Neira *et al.* (2008).

Region	Sex	Size at maturity				Age at maturity			
		N	**a**	**b**	**L_{50} (mm)**	**N**	**a**	**b**	**t_{50} (yrs)**
Eastern Tasmania	female	60	–16.81	0.11	157	141	–3.29	1.66	2.0
	male	594	–13.58	0.09	147	170	–3.20	1.58	2.0
South-western Tasmania	female	654	–12.68	0.05	261	133	–2.09	0.52	4.1
	male	128	–12.47	0.05	244	111	–3.00	0.62	4.8

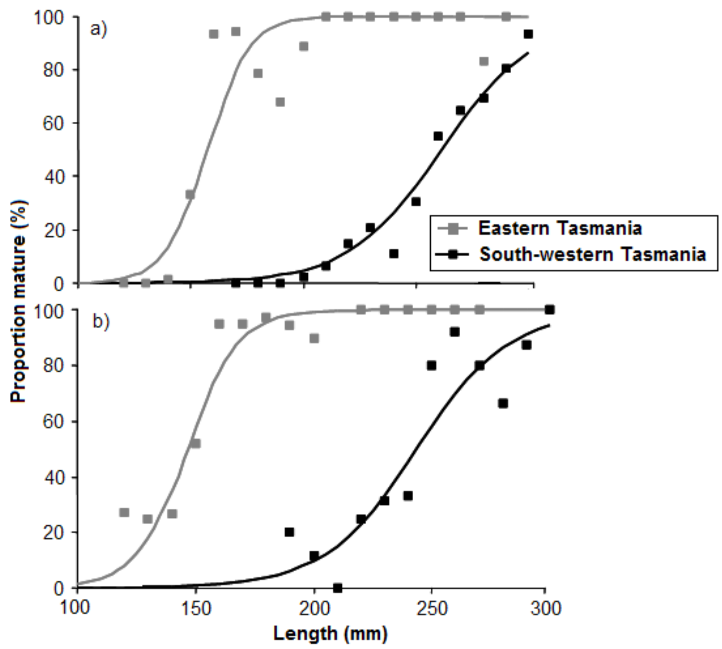

Figure 4.18 Proportion of mature female (a) and male (b) Redbait by length class and region, with logistic ogives fitted. Based on Neira *et al.* (2008).

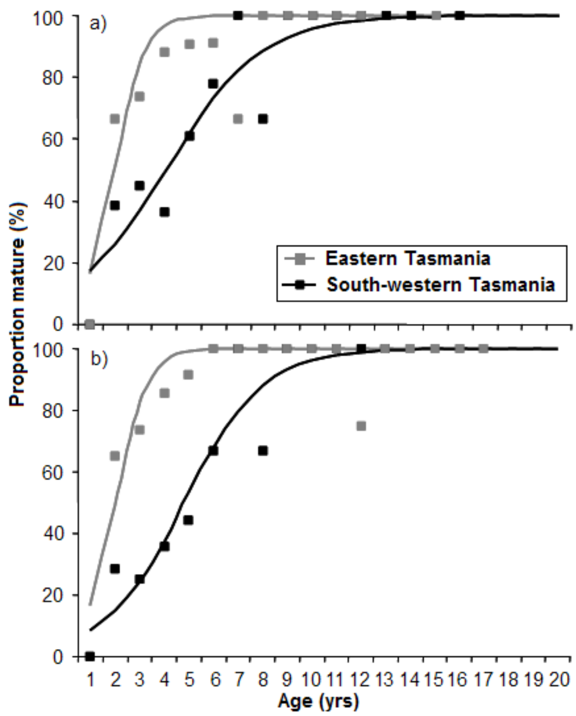

Figure 4.19 Proportion of mature female (a) and male (b) Redbait by age class and region, with logistic ogives fitted. Based on Neira *et al.* 2008.

4.3.3.5 Biomass estimates

Estimates of egg production, spawning area, mean female weight, batch fecundity, sex ratio and spawning fraction of Redbait were calculated from data obtained from concurrent ichthyoplankton surveys and commercial trawl operations in 2005 and 2006 (Neira *et al.* 2008). Mean daily egg production (P_0) was estimated using a non-linear least-squares regression (NLS) and a generalised linear model (GLM), and was based on two data scenarios; all eggs and a data set with extremes omitted. Extremes included eggs ≤4 hours old and eggs ≥98% of incubation time.

Main spawning areas within the surveyed area off the east coast of Tasmania were identified between north-eastern Bass Strait (38.8°S) and south of the Tasman Peninsula (43.5°S) in 2005 (13,220 km^2), and between Cape Barren Island (40.5°S) and the same southern boundary in 2006 (8,695 km^2). Redbait spawning biomass estimates computed using daily egg production estimates derived from NLS and GLM model fits varied between 66,000–143,000 t in 2005 and 43,000–58,000 t in 2006.

The 2005 NLS-based estimates were 25–65% higher than GLM-based estimates depending on the data scenario examined. By contrast, 2006 estimates were more similar in magnitude between models and data scenarios, although the GLM-based estimates tended to be slightly higher. Regardless of year or data scenario, GLMs proved to be a better fit to the data, returning lower coefficients of variation (see Neria *et al.* 2008). Overall, the GLM that omitted eggs with assigned ages <4 hours and >98% of incubation time provided the best fit and was adopted as the preferred model. Biomass estimates within respective spawning areas were 86,990 t in 2005 and 50,782 t in 2006.

4.3.3.6 MSE

For Redbait East, the DEPM estimate of spawning biomass was 23% of the model calculated estimate of spawning biomass. This is not an issue when investigating Tier 1 scenarios, as these are “relative” quantities determined as a percentage of the spawning biomass. The Tier 1 scenarios investigated using the MSE all reached an equilibrium at around B_{40} by the end of the 30 year simulation period. The Tier 2 and Tier 3 results suggest that these harvest levels are conservative and sustainable, however, these should be treated with caution as these harvest quantities are “absolute” quantities and represent a much smaller proportion of the model calculated biomass than the DEPM estimate of biomass.

The MSE results for Redbait West are similar to those of Redbait East. In this case there was no DEPM estimate of spawning biomass.

4.4 Summary and Conclusions

Although currently dated, DEPM estimates for Redbait in the East suggest a spawning biomass in excess of 50,000 t, implying that catches since 2001/02 (~7,000 t per annum) are sustainable, a view supported by the MSE. Recent low catches of Redbait East have been attributed to reductions in local abundance associated with increased water temperatures off eastern Tasmania. The eastern stock is therefore assessed as not overfished (Woodhams *et al.* 2012). In 2011/12, there were no reported landings of Redbait for either the East or West zones. As no estimates of spawning biomass have been made for the western stock Woodhams *et al.* (2012) suggested that it remains 'uncertain' whether overfishing is occurring or whether the stock is overfished. Biological sampling has revealed no obvious impact on size or age composition over the recent history of the fishery. There is no evidence to suggest that recent low catches of Redbait in either zone are not sustainable. The need to conduct DEPM assessments of Redbait in both zones warrants consideration.

5 AUSTRALIAN SARDINE (*SARDINOPS SAGAX*)

5.1 Introduction

5.1.1 Background to Fishery

Sardines (*Sardinops* spp.) form the basis of some of the world's largest fisheries (Schwartzlose *et al.* 1999) and have been the focus of extensive research where their fisheries are important (Stratoudakis *et al.* 2006). Australian Sardine (*Sardinops sagax*) occur in temperate waters from Queensland south to Western Australia (Ward and Staunton-Smith 2002) and several fisheries exploit them within this range.

Small scale exploitation of Sardine in Australia has occurred since the 1800s (Kailola 1993) but combined national catches did not exceed 1,000 t until the 1970s when several purse seine fisheries were developed out of ports in south-western Western Australia. The catch in Western Australia increased steadily until 1990 reaching ~8,000 t (Kailola 1993). In 1991, a dedicated Sardine fishery was established in South Australia to provide fodder for the tuna mariculture industry (Ward and Staunton-Smith 2002). Between 1993 and 2003 catches in this fishery ranged between 3500 and 6500 t. In 1995 and 1998, two mass mortality events affected all Australian Sardine populations, reducing biomass in South Australia by 75% and 70%, respectively (Ward *et al.* 2001a). The Sardine catch in Western Australia has not fully recovered since the mortality events with catches remaining below 2000 t since 1999 (Fletcher and Santoro 2008). The South Australian fishery however appears to have recovered relatively quickly with catch increasing to ~21,000 t in the 2002/03 season and subsequently remaining above 28,000 t (Knight and Tsolos 2012). Sardine catches from southern Queensland are not well recorded as prior to 1996 only small quantities were taken by beach seine nets to be used as bait (Ward and Staunton-Smith 2002). In 1996, a 3-year developmental fishery permit was issued for a single purse seine vessel to take 600 t of four small pelagic fish species, including Sardines (Ward and Staunton-Smith 2002). In 2000, purse seine fishing was prohibited in Queensland. The annual catch of Sardines in NSW has increased rapidly in recent years from historical averages of 30–40 t to more than 4,000 t in 2007/08.

5.1.2 Taxonomy

The Australian Sardine is broadly known as *Sardinops sagax*. Most fisheries scientists throughout the world follow the taxonomy of the genus *Sardinops* proposed by Parrish *et al*. (1989) who suggested the genus *Sardinops* is mono-specific with no valid sub-species. Recently, 11 new polymorphic micro-satellites were isolated that have the potential to resolve some of the minor taxonomic questions that remain regarding stock structure for this species (Pereya *et al.* 2004).

5.1.3 Distribution

Australian Sardine (*S. sagax*) is found in waters off Australia, Japan, North and South America, Africa and New Zealand. In Australia, it is found throughout temperate waters between Rockhampton (Queensland) and Shark Bay (Western Australia), including northern Tasmania (Gomon *et al.* 1994).

5.1.4 Stock Structure

There is a high level of genetic heterogeneity within the Australian stock of Sardine, but no evidence of spatially consistent stock structure (Okazaki *et al*. 1996; Ward *et al.* 1998). No detailed studies of stock structure have been undertaken across the distribution of Australian Sardine. Information on the movement rates of Australian Sardine across their distribution would assist future management. The most suitable approach to addressing questions of stock structure and movement rates would be in the context of an Australia-wide study that concurrently utilizes genetic, parasite and otolith based approaches that have recently been applied to several species of scombrids (see Buckworth *et al*. 2006; Ward and Rogers 2007).

5.1.5 Movement

Sardines are known to undergo extensive migrations. For example, schools of Sardines migrate north into waters off southern Queensland during winter-spring to spawn (Ward and Staunton Smith 2002). Similarly, off Africa, Sardines migrate north and south along the coast to access conditions that are favourable for spawning and the survival of recruits (van der Lingen and Huggett 2003). The movement patterns of Sardines in Australian waters are poorly understood.

5.1.6 Food and Feeding

Sardines switch between particulate-feeding on macro-zooplankton to filter-feeding on micro-zooplankton and phytoplankton, depending on relative prey density (van der Lingen 1994; Louw *et al.* 1998). In a recent study in South Australian waters, Australian Sardine were found to have consumed 12 prey taxa with krill (29.6% biomass) and unidentified crustacean (22.2% biomass) contributing the highest biomass (Daly, SARDI Aquatic Sciences unpublished data). Krill occurred in greater numbers (65.3%) than crustaceans (27.0%). Crab zoea, other decapods, copepods, polychaetes, fish eggs and larvae and gelatinous zooplankton were also present.

5.1.7 Age, Growth and Size

Australian Sardine growth rates and maximum size vary in response to localised variation in food availability and environmental conditions (Ward *et al.* 2003). In southern Australia, Australian Sardine rarely exceed 250 mm FL after 6 to 8 years (Rogers and Ward 2007). Larval and juvenile Sardine in southern Australian waters have growth rates of approximately 1.2 and 0.4 mm.day^{-1}, respectively (Rogers and Ward 2007). Rogers and Ward (2007) showed that the growth rates of Sardines are higher in South Australian waters than off other parts of the Australian coastline, yet lower than those in more productive boundary current ecosystems such as the Benguela, Agulhas and Californian systems. A notable finding of the study was that fish in commercial catches were younger (and smaller) than those obtained in fishery-independent samples.

5.1.8 Reproduction

The reproductive biology of Australian Sardines in some regions of Australia is relatively well known. Approximately 50% of males and females in South Australia reach sexual maturity (L_{50}) at 146 and 150 mm, respectively (Ward and Staunton-Smith 2002). Females spawn batches of 10,000–30,000 pelagic eggs approximately once per week during the extended spawning season. Eggs are abundant in the southern gulfs and shelf waters (Ward and Staunton-Smith 2002). Peak spawning season is variable across the Australian distribution of Sardines, for example in South Australia spawning occurs during the summer-autumn upwelling period of January-April (Ward *et al.* 2001b; Ward and Staunton Smith 2002), along the south coast of Western Australia spawning also peaks between January and June (Gaugan *et al.* 2002) and Sardines off Fremantle reached a maximum GSI during June (Murling *et al.* 2008). Along the east coast of Australia Sardine reach peak GSI in Victoria during spring-early summer (Hoedt and Dimlitch 1995; Neira *et al.* 1999), in southern Queensland peak GSI occurs in winter-early Spring (Ward and Staunton-Smith 2002). Off southern NSW peak GSI occurs between July and December (Stewart *et al.* 2010). Between 1989 and 1991, Sardine larvae were collected off Sydney during all months except March (Gray and Miskiewicz 2002).

5.1.9 Early Life History and Recruitment

Sardine eggs hatch approximately two days after fertilization and yolk-sac larvae are ~2.2 to 2.5 mm TL (Neira *et al.* 1998). Larvae metamorphose at 1–2 months of age and at lengths of 35–40 mm TL. Larvae are known to undertake vertical migrations that may reduce passive transport away from regions with environmental conditions that are favourable for survival (Watanabe *et al.* 1996; Logerwell *et al.* 2001; Curtis 2004). Sardine larvae are abundant at temperature and salinity fronts that form near the mouths of South Australia's two gulfs during summer and autumn (Bruce and Short 1990). Juveniles occupy nursery areas that include shallow embayments and semi-protected waters. The factors affecting recruitment success of Sardines are poorly understood.

5.1.10 Stock Assessment

The DEPM was developed to assess the status of northern anchovy *E. mordax* stocks off the coast of California (Lasker 1985; Parker 1980) and has been used to estimate the spawning biomass of Australian Sardine in South Australia since 1995. The advantage of this approach is that it provides direct estimates of spawning biomass on which to base management decisions. The disadvantages include the high degrees of uncertainty that surrounds the point estimates of biomass, high running costs of vessels, and extensive laboratory time required to identify eggs from ichthyoplankton samples (Cochrane 1999; Stratoudakis *et al.* 2006).

5.1.11 Management

A DEPM assessment has been conducted for the East zone and the fishery is managed at the Tier 2 level.

5.2 Methods

5.2.1 Fishery Statistics

Fishery statistics were supplied by ABARES up to 2010/11 and in 2011/12 data were supplied by relevant jurisdictions and collated by SARDI Aquatic Sciences. Annual data are in financial years. The absence of effort data from NSW means that no effort data can be presented for 2011/12.

5.2.2 Biological Information

Catch samples were collected from commercial landings at Eden and Illuka in NSW during 2009. Fish were dissected and morphometric data collected by NSW DPI, otoliths were interpreted for age by SARDI Aquatic Sciences using the methods of Rogers and Ward (2007). Additional size frequency data were supplied by NSW Fisheries and AFMA.

5.2.3 Biomass Estimates and MSE

A preliminary biomass estimate for Australian Sardine in the East was conducted in 2007 using ichthioplankton samples collected during July 2004 (Rogers and Ward

2007). Existing data and published parameter estimates were combined to provide best, minimum and maximum estimates of spawning biomass using the DEPM. Egg data were obtained from an ichthyoplankton survey conducted between Bundaberg and Newcastle during July 2004 as part of a study of Blue Mackerel, *S. australasicus*. NSW DPI provided some reproductive data for Australian Sardine off southern NSW. Other adult parameter estimates were collated from previous Australian studies of this species. The model was re-examined in 2011 to address concerns about values used for number of recruits.

5.3 Results

5.3.1 Fishery Statistics East

5.3.1.1 Location of vessels

The number of vessels that reported landings of Australian Sardine in the East was greater than the previous two years, and similar to the long-term average (Fig. 5.1). There was a marked increase in the proportion of vessels operating within Victorian waters, contrasting the historical trend of dominance by those from NSW.

5.3.1.2 Annual Patterns-catch, effort & catch-per unit effort

Catches of Australian Sardine in the East during 2011/12 decreased to 2,022 t, the lowest levels reported since 2003/04 (Fig. 5.2). Historically, catches remained below 1,000 t during the seasons between 1997/98 and 2001/02 before increasing rapidly to >4,000 t in 2005/06. Catches remained above 3,500 t until 2009/10 when they dropped below 3,000 t, increasing slightly during 2010/11 then decreasing to 2,022 t in 2011/12. Fishing effort peaked in 1999/2000 at ~5,000 vessel days before stabilising at ~3,000 days from 2000/01 to 2008/09 (Fig. 5.2). Effort dropped to <500 vessel days in 2009/10 and 2010/11 (Fig. 5.2).

While CPUE could not be calculated for the 2011/12 financial year, the trend over the two previous years demonstrate uncharacteristically high values (i.e., exceeding 10 t.vessel day^{-1}) when placed in an historical context (i.e., 12 year average of <2 t.vessel day^{-1}; Fig. 5.3).

5.3.1.3 Intra-annual Patterns-catch and effort

Intra-annual patterns of catch and effort have been variable across the data period with catches occurring in all months (Fig. 5.4). Annual peaks in catches were also irregular.

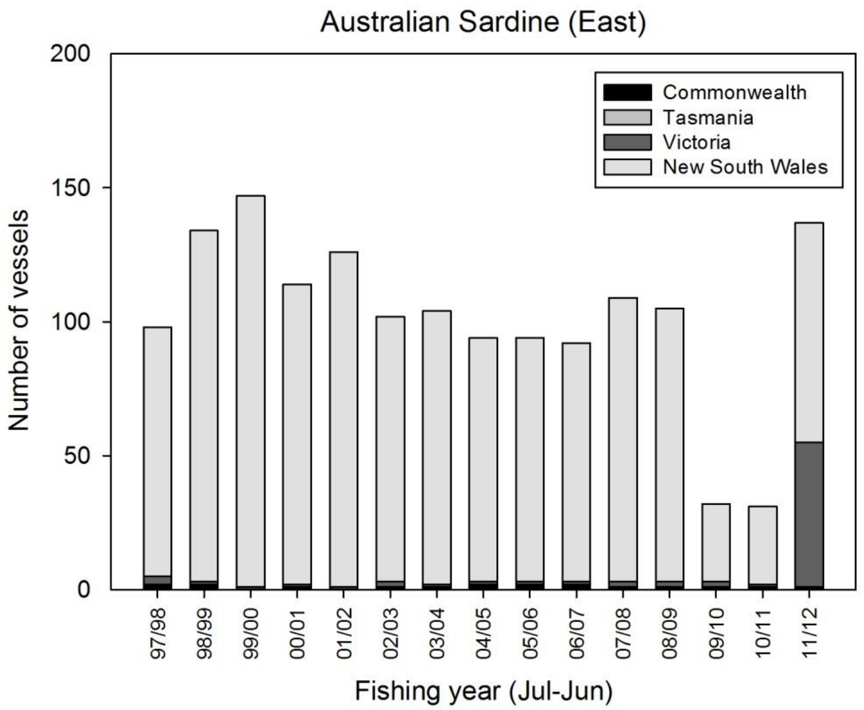

Figure 5.1 Number of vessels that reported landings of Australian Sardine in the East, from each of the participating management jurisdictions, during financial years over the period 1997/98–2011/12.

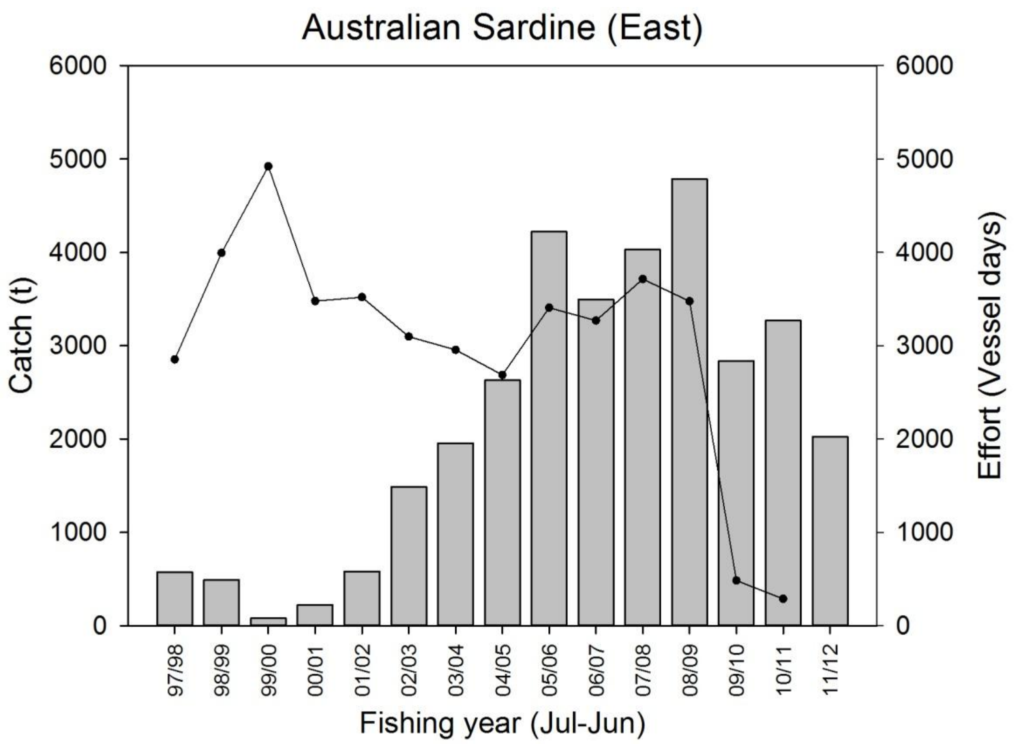

Figure 5.2 Total landed catch (t, bars) and effort (vessel days, line) for the East during financial years over the period 1997/98–2011/12.

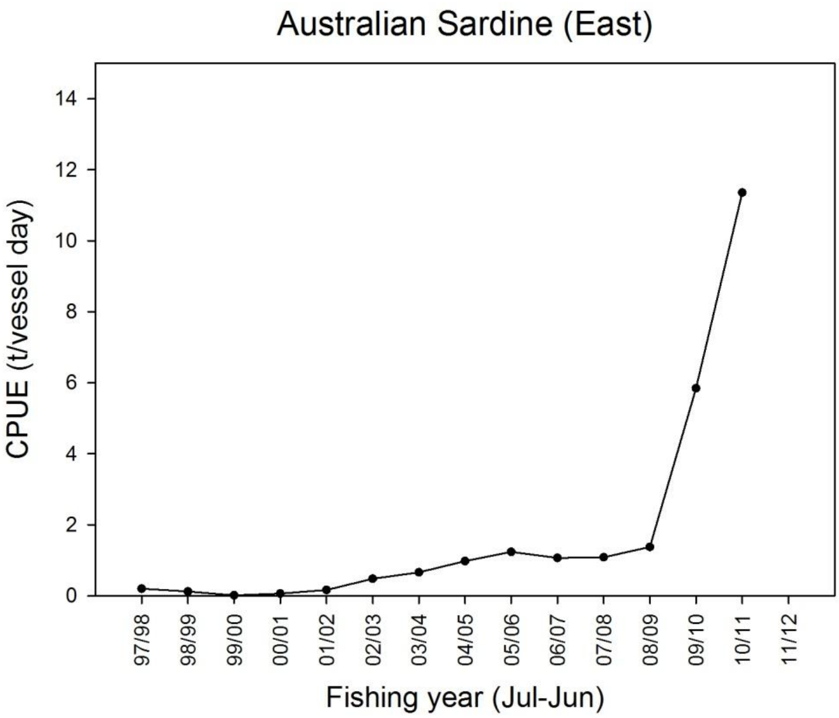

Figure 5.3 CPUE (t per vessel day) for the East during financial years over the period 1997/98–2011/12.

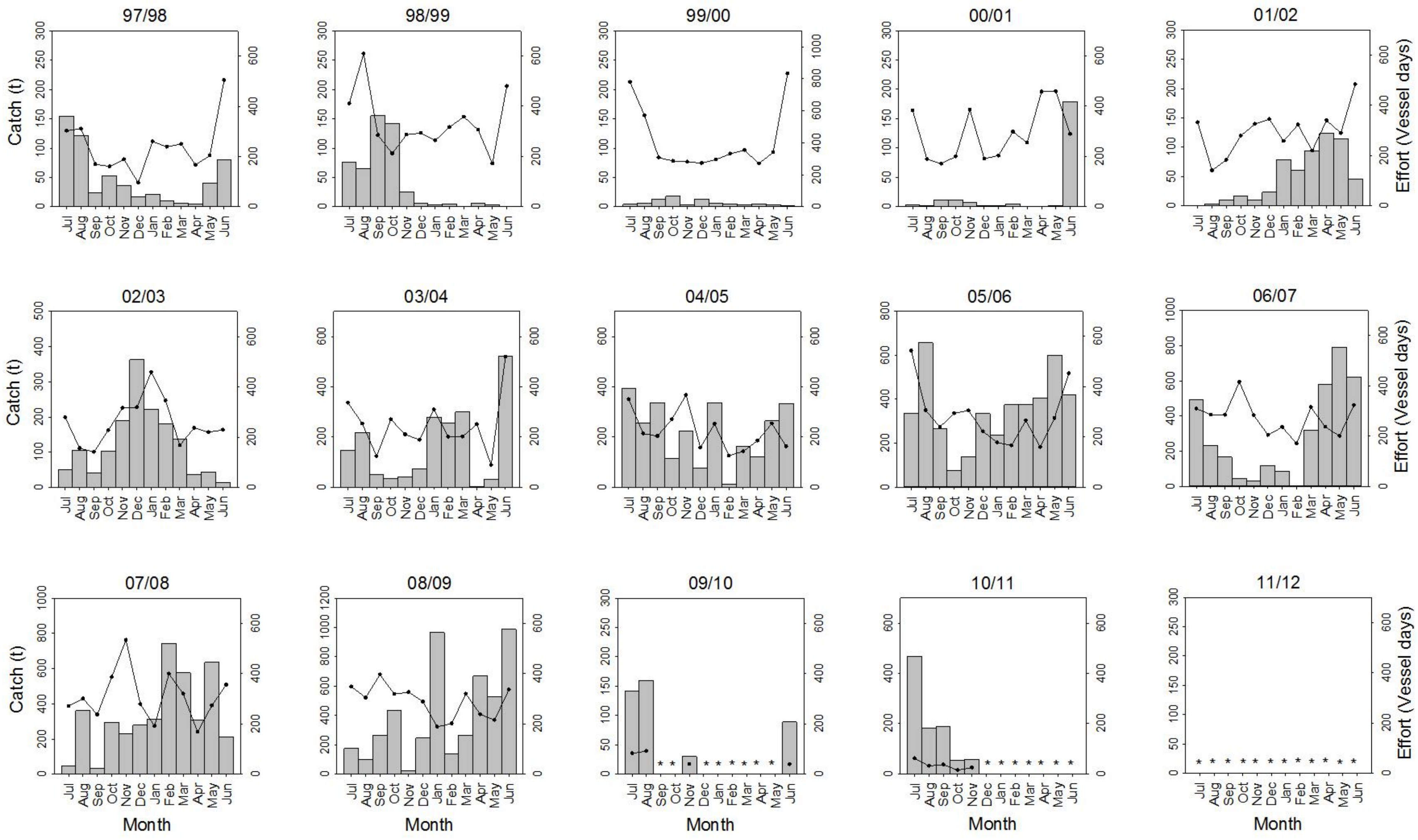

Figure 5.4 Intra-annual patterns of catch (bars) and effort (line) for Sardine for the East for the period from 1997/98 to 2011/12. (*) indicates data confidentiality, where <5 license holders report landings from individual month.

5.3.2 Biological Information

5.3.2.1 Sample Summary

A total of 1,028 Australian Sardine were collected from commercial fishers in NSW for biological analysis during 2009 and 2010 comprising 240 from the north coast (Illuka) and 788 from the south central coast (Eden). These samples represented three months from the north coast and eight months from the south central coast (Table 5.1). Length frequency data for an additional 12,060 *S. sagax* landed in NSW between 2004/05 and 2011/12 were supplied by NSW DPI. Length data for a further 208 Australian Sardine measured by AFMA observers in September 2012 were provided to SARDI; a sub-sample of 34 of these fish were made available for biological analysis.

Table 5.1 Spatial and temporal summary of data supplied to SARDI for biological analysis.

Month	North Coast	South Central Coast
March 2009		8
June 2009		70
July 2009	120	160
August 2009	80	100
September 2009	40	151
October 2009		120
November 2009		79
January 2010		100

5.3.2.2 Size Structure

Most Australian Sardines taken in NSW in 2009/10 were between 120 and 200 mm (Figs. 5.5, 5.6). Samples from both the north and south central regions tended to have smaller fish at the beginning of the season. The length distribution of annual (financial year) Australian Sardine catches were bimodal from 2004/05 to 2006/07 (Fig. 5.7), with the smaller mode around the size at maturity. Length distributions for 2009/10 and 2010/11 were unimodal with the mean size above the size at maturity (Fig. 5.7). In 2011/12 the length frequency was bimodal with ~50% of fish sampled below the size at maturity.

The size frequency of fish sampled from commercial vessels by AFMA observers on the north coast of NSW in September 2012 (Figure 5.8) had a mode at 15 cm FL.

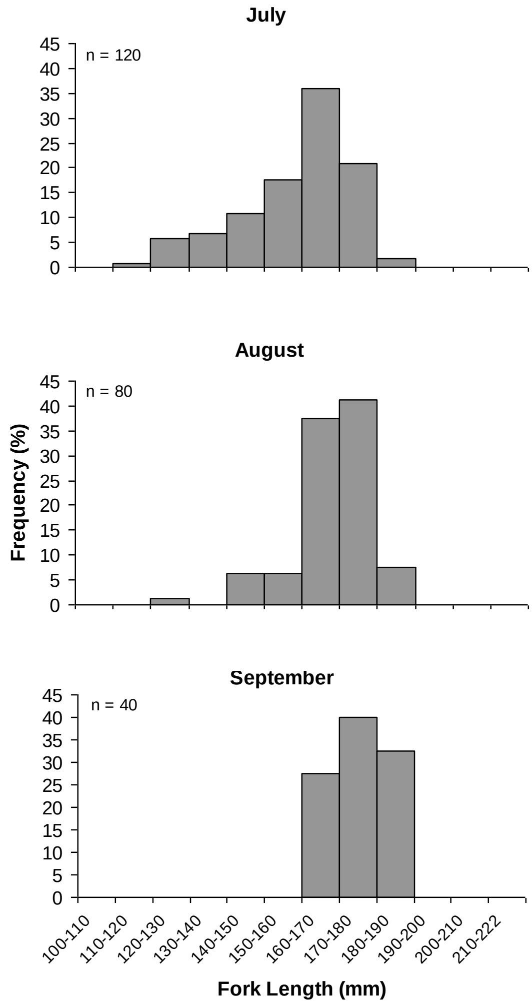

Figure 5.5 Size frequency histograms for Australian Sardine samples from commercial catches from the north coast of NSW in 2009.

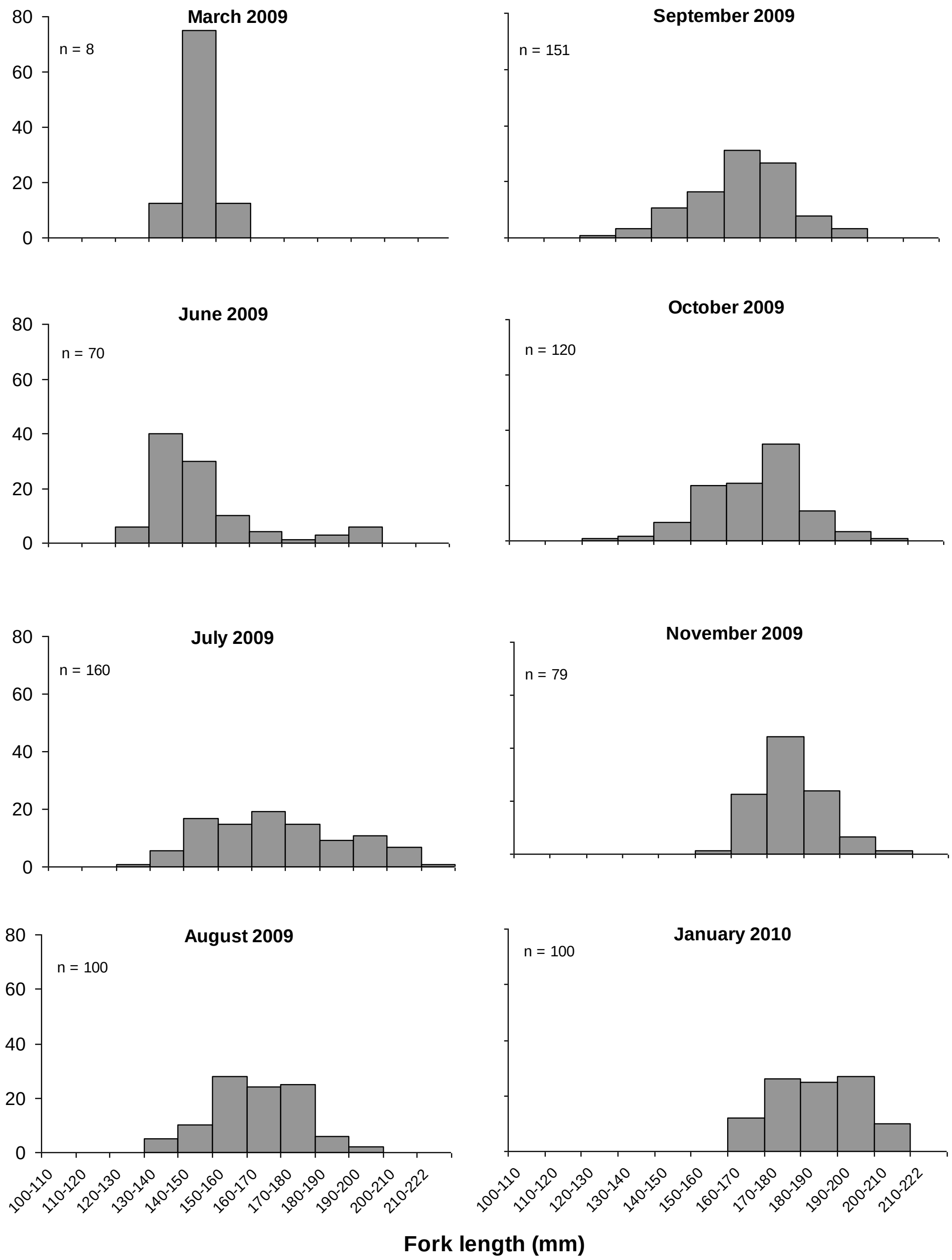

Figure 5.6 Size frequency histograms for Australian Sardine samples from commercial catches from the south central coast of NSW in 2009 and 2010.

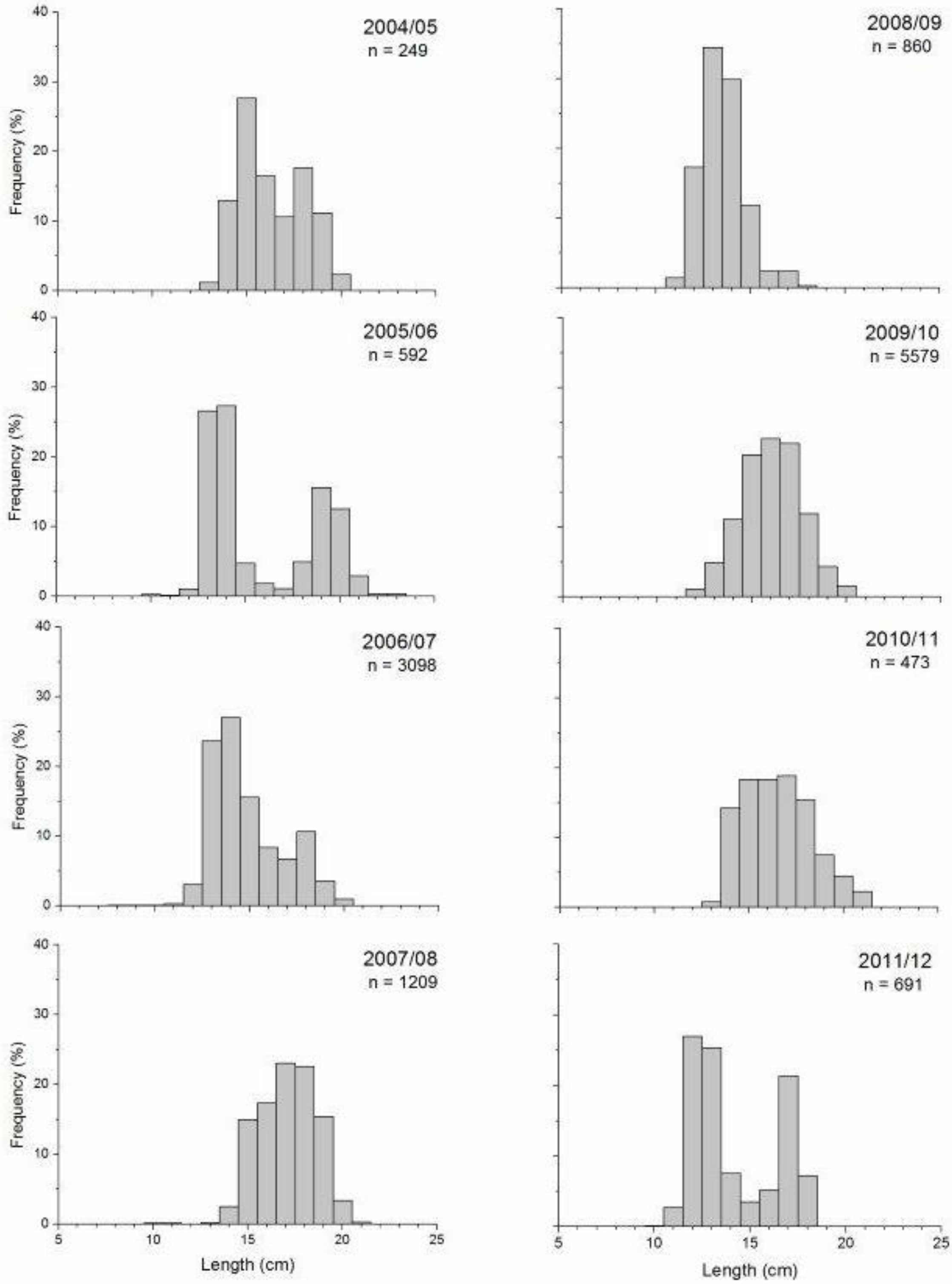

Figure 5.7 Length frequencies of commercial catches of Australian Sardine for the northern (since 2008/09) and southern regions of NSW combined. Weighted against the size of landings (data supplied by NSW Department of Primary Industries).

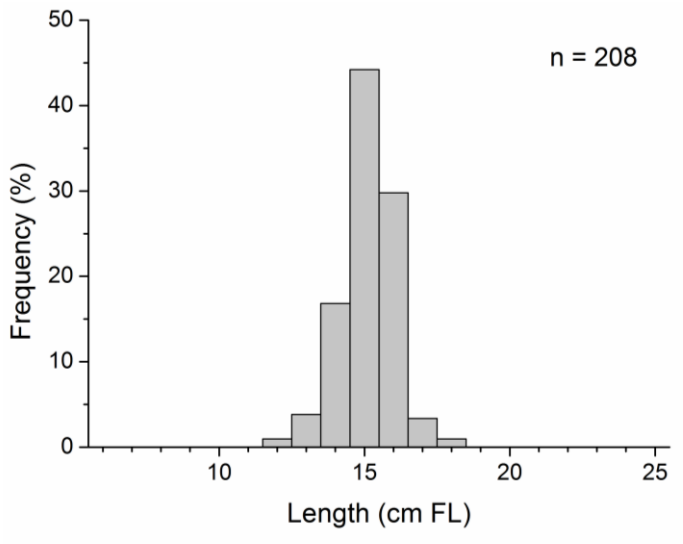

Figure 5.8 Length frequency of commercial catches of Australian Sardine collected by AFMA observers during September 2012 on the north coast of NSW.

5.3.2.3 *Age structure*

Commercial samples from the south central NSW coast in 2009 ranged from 0 to 5 year olds, whereas catches from the northern region consisted of 0 to 3 year olds (Fig. 5.8). Commercial samples from northern NSW in September 2012 were predominately comprised of 2 year old fish (Figure 5.10).

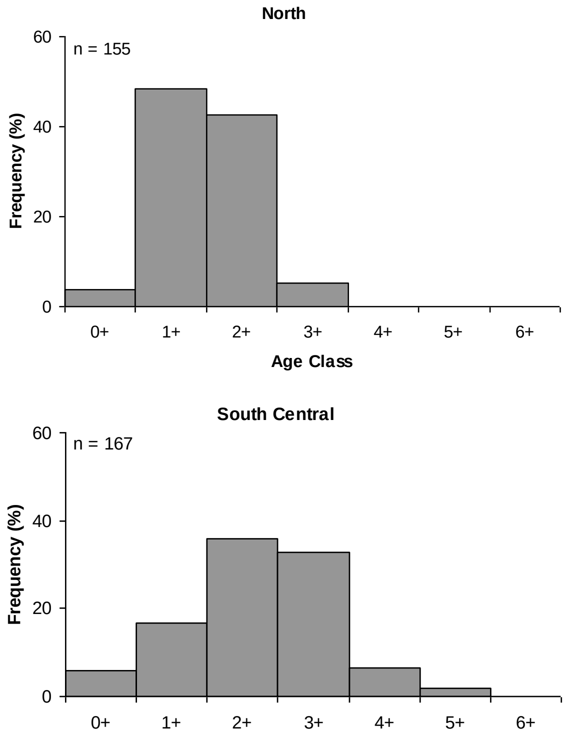

Figure 5.9 Age frequency histograms for Australian Sardine samples from commercial catches from the south central and north coast of NSW in 2009. Data derived from ring count analysis. Otoliths of poor readability (readability index 4 and 5) were omitted.

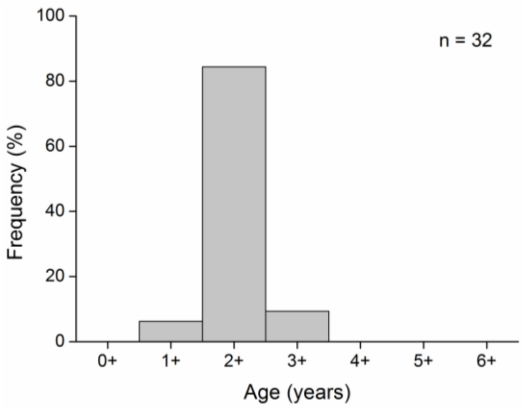

Figure 5.10 Age frequency histogram for Australian Sardine collected from commercial vessels on the north coast of NSW in September 2012. Ages are derived from the otolith weights using the South Australian commercial catch relationship (Rogers and Ward 2007).

5.3.2.4 Growth Patterns

The growth patterns for Australian Sardines collected from both the north and south central coasts of NSW were similar (Fig. 5.11). Both exhibited considerable variation in size for each of the age classes.

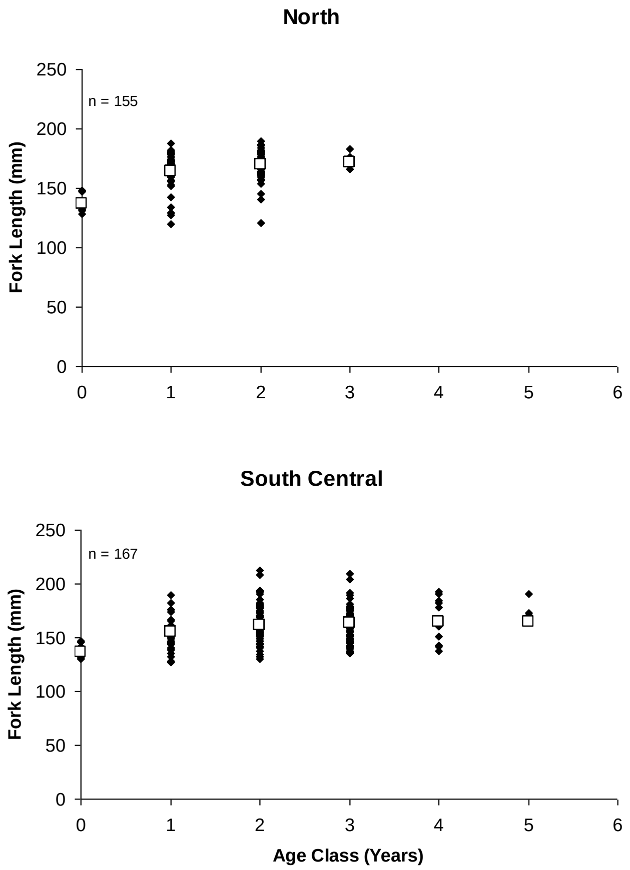

Figure 5.11 Growth patterns for Australian Sardines collected from commercial catches from the north and south central coast of NSW in 2009. Ages derived from ring count analysis, otoliths with poor readability (readability index 4 and 5) were omitted. Open squares generated from von Bertalanffy growth function.

5.3.2.5 Gonad stages

Samples from both the north and south central coast were comprised predominately of mature fish (> stage I) across the sampling period (Fig. 5.12). Insufficient numbers of immature fish were collected to allow size at maturity to be determined. Actively spawning females (stage IV) were collected from the north coast in all months sampled (July, August and September) and in June, July and August on the south central coast.

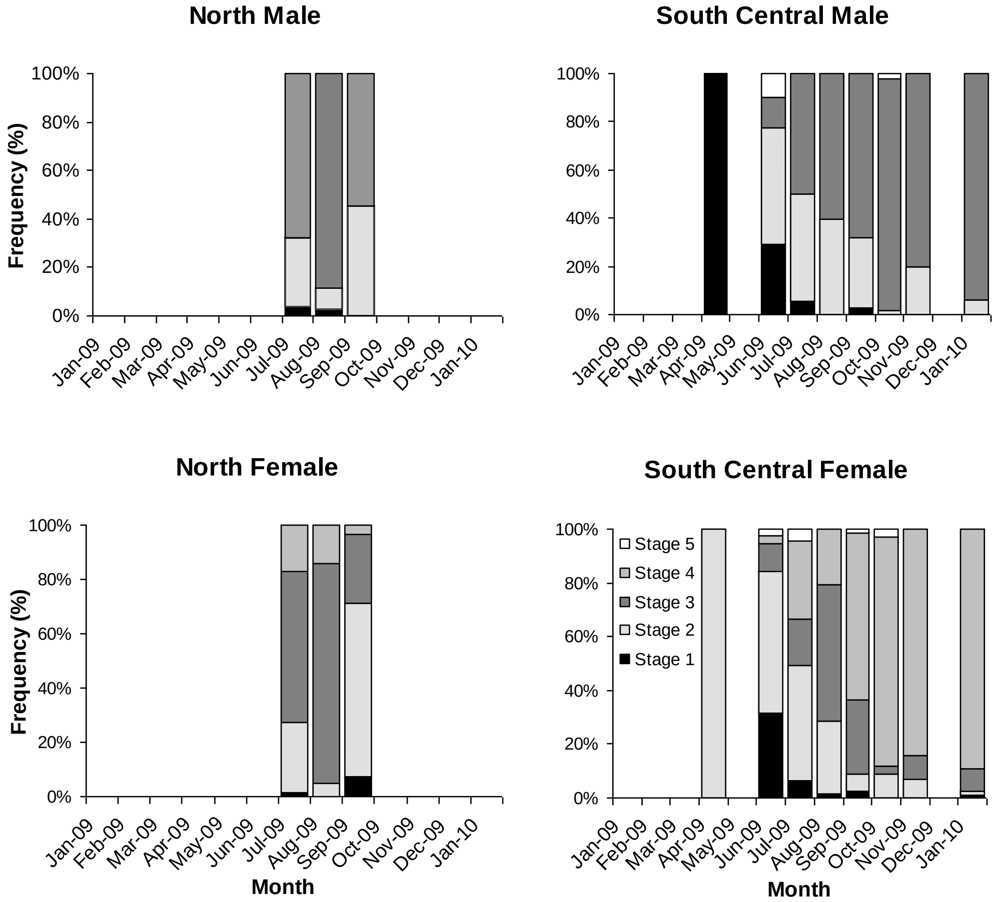

Figure 5.12 Frequency of occurrence of each stage of gonad development for monthly sampling of Australian Sardine from both the north and south central coast of NSW. Number for each month are shown in Table 5.2.

5.3.2.6 Sex ratio

The sex ratio for all months and regions was biased towards females (Table 5.2).

Table 5.2. Sex ratio (R) of Australian Sardine samples taken in the 2009/10 fishing season.

	South Central			North		
Month	**Female**	**Male**	**R**	**Female**	**Male**	**R**
March 2009	6	2	0.75			
June 2009	38	31	0.55			
July 2009	108	52	0.68	70	50	0.58
August 2009	67	33	0.67	43	35	0.55
September 2009	80	70	0.53	28	11	0.72
October 2009	68	52	0.57			
November 2009	44	35	0.56			
January 2010	83	17	0.83			
Total	494	292	0.63	141	96	0.59

5.3.2.7 Gonosomatic index

GSI was generally higher for both males and females from the north coast (Fig. 5.13), with the highest GSI for males recorded in August for both regions. GSI for females was highest in September on the north coast and July on the south central coast (Fig. 5.13).

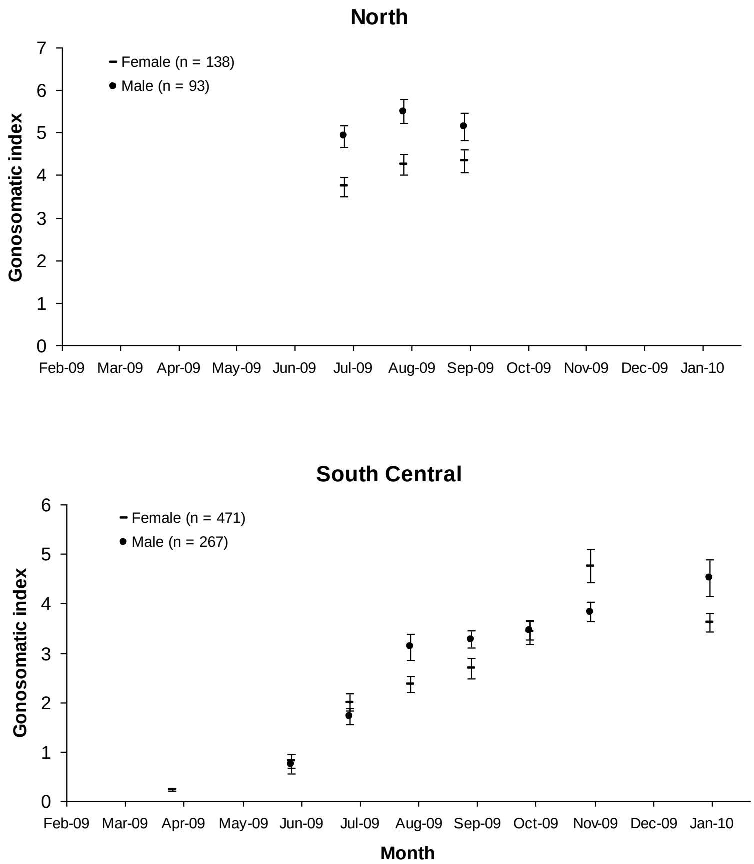

Figure 5.13 Monthly gonosomatic index for Australian Sardine from the north and south central coast of NSW. Error bars are standard error. Immature fish (stage 1) have been omitted from data.

5.3.2.8 DEPM

The total area sampled during the July 2004 ichthyoplankton survey was ~41,585 km^2. A total of 2,441 Australian Sardine eggs was collected from 85 stations. High densities of eggs were recorded between Cape Byron and Newcastle.

The best estimate of spawning area obtained using the Voronoi near neighbour method (Ward *et. al.* 2007) to estimate grid size was 9,363 km^2. Spawning may have occurred south of the area surveyed. The best estimate of mean daily egg production

(P_0) obtained using the linear version of the exponential mortality model was 69.96 eggs.day^{-1}.m^{-2}. Best estimates of reproductive parameters were: female weight, W = 51.35 g; sex ratio, R = 0.56; spawning fraction, S = 0.14; and batch fecundity, F = 15,108 hydrated oocytes.

The best estimate of spawning biomass off eastern Australia during July 2004 was ~28,809 t. Minimum and maximum estimates were 9,161 and 58,673 t, respectively. Spawning biomass estimates were relatively insensitive to variations in spawning area, female weight, sex ratio and batch fecundity. Only unlikely values of mean daily egg production and spawning fraction produced estimates outside the range of 25,000–35,000 t. This estimate is conservative and likely negatively biased as spawning season and area varies temporally and spatially on the east coast of Australia (Ward and Staunton-Smith 2002) and it is not likely the entire spawning area was sampled in peak spawning season.

Estimates of spawning biomass provide a context for assessing the suitability of recent catch levels. The highest annual catch of ~5,000 t is ~17.4% of the best estimate of spawning biomass, suggesting that fishing is being conducted within sustainable limits.

5.3.2.9 MSE

For Australian Sardine East, the DEPM estimate of spawning biomass was 96% of the model calculated estimate of spawning biomass. The Tier 1 scenarios investigated using the MSE all reached equilibrium at around B_{60} by the end of the 30 year simulation period. The Tier 2 and Tier 3 results suggest that these harvest levels are also sustainable. Given that the DEPM survey estimate of spawning biomass is close to the model calculated estimate, these conclusions can be considered with greater certainty than for the other SPF species.

5.4 Summary and Conclusions

The best estimate of spawning biomass of Australian Sardine off eastern Australia during July 2004 was ~29,000 t. However, as the entire spawning area was not surveyed the spawning biomass may have been under-estimated. Catches of Australian Sardine in the East zone remained below 1000 t up to 2001/02, but exceeded 2,000 t in 2004/05 and reached almost 5,000 t in 2008/09. Catches were ~3,000 t during 2009/10 and 2010/11 then declined to 2,022 t in 2011/12. These catches come from fisheries managed separately by three jurisdictions (NSW, Victoria and the Commonwealth).

The recent reduction in effort in Australian Sardine East appears to reflect a change in the way effort is categorised in the NSW Ocean Haul Fishery, rather than a reduction in fishing activity. Limited catch samples were available for 2011/12. Other than the apparent decline in sardine availability off southern NSW, which may be driven by oceanographic conditions, there is no evidence to suggest that the current catch level of Australian Sardine in the East is not sustainable. Woodhams *et al.* (2012) assigned Australian Sardine to the categories of ‘not overfished’ and ‘not subjected to overfishing’. Flood *et al.* (2012) classified the stock status of Australian Sardine as ‘sustainable’ in all regions. As identified in previous reports, the need for further DEPM assessments of Australian Sardine in the East zone warrants consideration.

6 GENERAL SUMMARY AND CONCLUSIONS

Catches of Blue Mackerel, Jack Mackerel and Redbait in 2011/12 were low (i.e. below the Tier 2 maximum RBCs) in both the West and East zones of the SPF. There is no evidence to suggest that this reduction in catch reflects a decline in the abundance or overfishing of any of these stocks. The reductions in catch appear to be driven by market constraints. These three species have been classified as 'not over-fished' in both zones, except Redbait West which has been classified as 'uncertain' (Woodhams *et al.* 2012). There is no evidence to suggest that recent low catches of these species are not sustainable.

The Australian Sardine catch taken from the East in 2011/12 (2,022 t) is below the RBC for this species (3000 t). This stock has been classified as 'not overfished' (. There is no evidence to suggest that the current catch level of Australian Sardine in the East zone is not sustainable and has been classified as 'not overfished' (Woodhams *et al.* 2012; Flood *et al.* 2012).

Current understanding of the abundance of SPF species in both zones is limited by the increasingly long period since DEPM surveys have been conducted. Consideration should be given conducting additional dedicated multi-species DEPM surveys in both zones to update the biomass estimates for SPF species. The large size of the West zone makes assessment of that area logistically difficult. Consideration should be given to sub-dividing the West zone for the purposes of stock assessment and management.

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